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POLICY IMPACTS OF ATC AUTOMATION: HUMAN FACTORS CONSIDERATIONS.(U)

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POLICY IMPACTS OF ATC AUTOMATION: HUMAN FACTORS CONSIDERATIONS

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16. Abstract This report examines

This report documents work performed for the Federal Aviation Administration (FAA) to study the future policy impact implications of advanced air traffic control (ATC) systems which might be developed by the (FAA). ~~The study examined~~ studies impacts of ATC automation on sector air traffic controllers, with emphasis placed on the identification of human factors problems that may arise in the future if higher level of automation~~s~~ are implemented. Of particular concern are those human factors that may in some manner determine the direction of automation development or impede the implementation of automation. Questions relating to the feasibility of hardware and software design were not addressed; automation configuration concepts were assumed to be technologically feasible. Using descriptions of technological components currently proposed by the FAA, six ATC system operations were defined. These systems represent various levels of automation development from the current system to a system in which the human controller acts as a systems data manager. The systems were evaluated in terms of 17 factors describing job satisfaction and motivation, man-machine interface, and failure mode operations in order to identify critical operational characteristics for each system.

17. Key Words
Air Traffic Control (ATC), Policy Issues, Automation, Controllers, Human Factors

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EXECUTIVE SUMMARY

The study described in this report is part of a broad effort by the Federal Aviation Administration (FAA) to investigate the long-term policy issues and potential impacts of higher levels of air traffic control (ATC) automation. The broad effort is concerned with identifying and determining the scope of problems of organizational and institutional policy formulation that may face the FAA in the future. This research is a pilot effort to investigate the human factors impacts of future automation on sector controllers. The research examines human factors influences on the degree to which ATC automation may ultimately be developed, the likely paths of automation transition, and the types of controllers most amenable to interface with highly automated operations.

A. Method of Approach

Six sector control operations representing the current ATC system and five plausible versions of future automated systems were defined, and 17 factors describing the pertinent performance capabilities of humans were selected. Each future system was rated relative to the present system in terms of the factors by a panel of FAA and other government personnel familiar with ATC.

1. System Descriptions

Descriptions of future ATC systems were developed by projecting logical representatives of system operating functions corresponding to various advanced technology configurations. These descriptions were based on operational characteristics analogous to those of the current ATC system, which includes National Airspace System (NAS) Stage A and Automated Radar Terminal (ARTS) technologies. Operational descriptions were developed for the following six systems:

- System 1: NAS/ARTS
- System 2: Enroute Decision Aid Automation
- System 3: Terminal Decision Aid Automation
- System 4: Control-by-Exception--Level I
- System 5: Control-by-Exception--Level II
- System 6: Control-by-Exception--Level III.

a. System 1: NAS/ARTS--NAS/ARTS operations require terminal and enroute controllers to perform traffic planning, tacital decision making, and clearance issuance functions. Clearances are issued by the controllers using air/ground (A/G) voice communications.

b. System 2: Enroute Decision Aid Automation--Enroute decision aid automation incorporates conflict probe and related technologies to automate tactical decision making but requires enroute controllers to critically review the computer-generated tactical decision-making activities. Clearances are issued through A/G voice communications.

c. System 3: Terminal Decision Aid Automation--Terminal decision aid automation incorporates metering and spacing and related technologies to automate traffic planning and tactical decision-making functions but requires terminal controllers to critically review the computerized traffic planning and tactical decision-making activities. Clearances are issued through A/G voice communications.

d. System 4: Control-by-Exception--Level I-- Control-by-exception (Level I) incorporates control message automation (CMA), data link, and related technologies to automated traffic planning, tactical decision-making, and clearance issuance functions, but requires terminal and enroute controllers to critically review the computerized planning actions and tactical decision-making and clearance issuance activities. Clearances are automatically processed by data link.

e. System 5: Control-by-Exception--Level II--Control-by-exception (Level II) incorporates the same basic technologies as Level I but requires controllers to maintain cognizance (i.e., without critical review) of computerized planning actions and to critically review computerized tactical decision-making strategies without reviewing the details of the automated clearance issuance activities.

f. System 6: Control-by-Exception--Level III--Control-by-exception (Level III) incorporates the same basic technologies as Levels I and II but requires controllers to maintain the computer data base without maintaining cognizance or critically reviewing-computer generated actions.

2. Human Factors Descriptions

Human factors pertinent to ATC operations were studied; the following 17 factors in the general areas of job satisfaction and motivation, man-machine interface, and failure mode operations were selected on the basis of their relevance to future ATC automation issues:

Job Satisfaction and Motivation

1) Achievement--work alignment
2) Recognition
3) Responsibility
4) Control authority
5) Utilization of perceived skills
6) Challenge--discretionary flexibility
7) Performance feedback
8) Interest

Man-Machine Interface

9) Vigilance
10) Stress
11) Intricacy
12) Restrictiveness
13) Rigidity
14) Decision making

Failure Mode Operations

15) Failure recognition
16) Failure recovery
17) Failure operations

B. Conclusions

The functional descriptions of each system were rated relative to the human factors in such a manner that the respondents could state their evaluations of desirable and undesirable job elements. Project staff analyzed the resultant rating data to identify those operational characteristics of ATC systems that were perceived by the raters as significantly weak or strong. The results of this analysis are described in the main body of this report; a summary of our conclusions is presented below.

System 2 (Enroute Decision Aid Automation) was found to be the most promising of the future systems in terms of compatability between operational design and human factors. The conflict probe of System 2 would enable a controller to apply expert skills to critically review computerized actions and therefore would not severely limit his ability to exercise highly trained capabilities. System 6 (Control-by-Exception, Level III), in which a controller is almost completely "out of the loop" but acts as the overall systems manager, would be acceptable given a radical change in the type of person performing the job as well as in the training he receives. This of course assumes technological components of such quality and redundancy that a controller could be removed completely from the tactical ATC situation.

System 3 (Terminal Decision Aid Automation), System 4 (Control-by Exception, Level I), and System 5 (Control-by-Exception, Level II) reduce the opportunities of today's controllers to apply their expert skills, and

thus lead to inconsistencies between human expectations and rewards. In these systems, highly trained control skills equivalent to those of today's controllers would be necessary if the controller is expected to perform recovery operations in the event of automation failure. Underutilization of these expert skills, caused by removing the planning functions from the job responsibilities of controllers, appears to account in large part for reductions in job satisfaction and motivation rewards. Such underutilization of expert skills could also undermine the capabilities of controllers to respond to failures regardless of the amount of training they have received.

The conclusions discussed above are based on a preliminary research effort that requires further verification. This initial research utilized a panel of raters composed of individuals with long experience in air traffic control and others with backgrounds in engineering, medicine, psychology, and personnel. A replication of the research utilizing a panel composed of air traffic control personnel at FAA ATC facilities would be desirable. Also, the list of human factors involving job satisfaction used in this research omitted such considerations as job advancement potential, financial remuneration, and on-the-job interpersonal relationships. These considerations involve complexities that are beyond the scope of this first-cut analysis and were therefore not included.

ACKNOWLEDGMENTS

During this project a rating session was held at which FAA and TSC staff members participated in a structured evaluation of alternative air traffic control system concepts. This rating session required considerable concentrative effort on the part of raters, and we are indebted to their highly cooperative attitude. The raters, along with their DOT organizational unit code, are listed below in alphabetical order:

Name	DOT Organization
Adams, H.	AVP-200
Alvania, S.	AVP-210
Aronson, N.	AVP-210
Bierach, K.	AEM-100
Cooper, R.	AAT-336
Copeland, J.	AVP-110
Dailey, J.	AAM-310
Dumas, J.	TSC-53
Felbinger, R.	APT-20
Gerathewohl, S.	AAM-110
Hodge, D.	AAT-320
Huber, E.	APT-220
Karsten, P.	ANA-110
Maclennan, H.	AAT-520
Merrick, F.	AAT-120
Milligan, H.	ANA-4B
Petruzel, W.	ARD-150
Robertson, A.	TSC-53
Simeon, A.	AAT-530
Wainwright, R.	AAT-110

We wish to thank the project technical monitors, Mr. Horace O. Adams and Mr. Nathan Aronson, of the FAA's Office of Aviation Policy, for their guidance in organizing this research and their assistance in reviewing and constructively critiquing the project efforts. We would also like to thank Mr. John Rogers, of the same office, for reviewing the project results.

Dr. George J. Couluris, of SRI's Transportation and Industrial Systems Center, was the project leader under subcontract to Payne-Maxie Consultants and developed the descriptions of postulated air traffic control systems. Dr. Michael G. Tashker directed the development of human factors descriptions, designed the scoring questionnaires, and performed a significant portion of the data analysis effort. Mr. Michael C. Penick directed the data reduction effort. Dr. Robert S. Ratner, the Center's Director, provided supervisory review. SRI staff members Dr. Paul L. Tuan and Dr. James Ketchel contributed to the development of research methodologies.

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I INTRODUCTION

The path of evolution of air traffic control (ATC) modernization and automation leads to increased employment of sophisticated system technology. A number of engineering and operational studies have predicted that deployment of new systems hardware and software will have a significant effect on the way control services are performed and delivered to system users.[1-16*] These technological developments encompass changes to communications, surveillance and navigation procedures, separation standards, airspace sectorization, sector control equipment, sector manning strategies, and airspace traffic flow regulations. Analyses of the operational potentials of various technological components have resulted in proposals for future system designs. These ATC system plans include the Upgraded Third Generation (UG3RD),[1-3] Extended UG3RD,[4] and Advanced Air Traffic Management System (AATMS)[5,6] concepts.

Studies of the operating capability of various systems have projected moderate to sizeable gains in traffic capacity and controller productivity.[1-12] However, the successful implementation and continued operation of future ATC systems depend not only on the resolution of technological problems but also on the development of systems that are compatible with organizational and institutional processes. Deployment of advanced technology by the Federal Aviation Administration (FAA) will probably require modifications to the agency's organizational behavior in order to adjust to both the operational characteristics of new systems and the reactions from the aviation industry, the public, and other government agencies. Therefore, there is reason to believe that implementation of new ATC systems will both require and induce changes in the processes by which the FAA functions. Operational impacts would be felt in such areas as policy review, program planning, resource allocation, and management of ATC services and regulatory responsibilities.

Although most studies of future ATC automation have concentrated on questions of technological and operational feasibility a few have examined some aspects of organizational and institutional questions by addressing the problem of human behavior in automated operations.[17,18] These studies, however, have not given full attention to the possible impacts on controllers of future automation and the possible human and other organizational limitations to the successful implementation of ATC automation. Clearly, additional research is needed to determine the degree to which ATC can be and should be automated.

In response to the concerns stated above, the study described in this report was undertaken.

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*A list of references is attached to this report.

A. Objectives and Scope

This study is a pilot effort to develop methodology and guidance for further analysis of future automation policy issues and preliminary information describing possible problem areas. The scope of the study was restricted to human factors issues relating to the impacts of ATC automation on sector controllers. The emphasis of the research was on identifying problems that may arise in the future if higher levels of automation are implemented. Of particular concern were those human factors issues that may in some manner determine the direction or impede the implementation of automation. Questions relating to the feasibility of automation hardware and software design were not addressed; automation configuration concepts were assumed to be technologically feasible.

B. Method of Approach

The study was designed as a first-cut analysis of the role human controllers might have in future operational environments. The analysis focused on the interactions between humans and various automation concepts so that human capabilities and limitations could be better understood. This approach was intended to broaden insights into human factors issues concerning the degree to which ATC automation may ultimately be developed, the desirable paths of automation transition, and the types of human controllers most amenable to interface with highly automated operations.

To search for and identify relevant issues, the project team developed a methodology to evaluate the human factors consequences of future automation. Plausible ATC systems that could be examined for their effects on human factors were developed. For each system, functional descriptions of future automated operations were compared with 17 human factors, and the system operations were subjectively rated relative to these factors. The rating procedure was designed as a series of critical questions that tested such human factors as motivation, achievement, responsibility, challenge, stress, and the like against a set of specific automation functions. The questions enabled persons familiar with ATC operations to rate their perception of the degree of importance of each human factor for specific ATC environments.

The ratings were performed by government personnel using system functional descriptions, factor descriptions, and rating forms developed by the project team. Project personnel administered the rating exercise and reduced and analyzed the data but did not participate in the rating.

1. System Descriptions

Project personnel developed descriptions of future ATC systems by projecting logical representations of system operating functions corresponding to various advanced technology configurations. The descriptions of future systems are hypothetical but are based on extensions of ATC automation

currently being proposed or developed by the FAA[1-3] and on related studies[4-6] of advanced ATC system designs and operating strategies. These advanced systems assume an evolutionary deployment of new technology and the continuation of the current philosophy of ground-based air traffic management with a high degree of tactical and strategic control automation. The high levels of automation allow the human operator to function as an air traffic monitor and manager rather than as a controller of minute-by-minute air traffic events.

Past studies have discussed the role of man as a manager, but not at the level of descriptive detail needed to perform the human factors analyses required for this research.[4-6] Therefore, project personnel incorporated and integrated the technological descriptions contained in these studies and projected alternative operating modes for both human operators and automation. The system descriptions developed represent alternative design concepts that are being considered for future implementation; they do not represent official FAA views and positions. Changes to the current concepts of technological development should not significantly affect the outcome of this tudy, however, because the systems analyzed are representative of technology trends.

Six automated sector control operations were identified including the current ATC system and five future systems. The future systems were postulated by configuring various automation components proposed by the FAA[1-3] into advanced systems whose operational characteristics are analogous to current systems. The analogies were based in part on available documentation of operational concepts[4-6] and in part on operational knowledge accumulated through a series of previous ATC studies[7-12] that included on-site observations of FAA enroute and terminal control facilities.

Three of the future ATC systems were collectively referred to as control-by-exception* operations. These assumed the use of automatic control message generation and transmission technology. In control-by-exception systems, sector controllers can intervene in the computerized control operation when they take exception to or disagree with the automation's intended actions. The three control-by-exception systems were defined according to three distinct levels of human intervention capability; the most advanced system allows virtually no human intervention and direction.

The two remaining future systems, enroute and terminal decision aid automation, represent intermediate technological developments that might precede control by exception. These two systems could be part of a time-phased evolution from the current ATC system to a control-by-exception system, although such evolutionary deployment is not a necessary premise for this study. The technological components of the six ATC systems are described in Section II of this report.

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*The term "control-by-exception" is not an official FAA identifier for any system, but it is in popular use. Other terms, such as "man-as-the-manager," are equally appropriate.

The operation of each ATC system was described in terms of the control processes required to perform traffic planning and tactical control services. The control processes were subdivided into a set of 30 control functions, each of which must be performed by a human or by the automation mechanism. Project personnel developed unique descriptions of control operations for each system by assigning specific functions to either a human operator or a machine depending on the automation composition of the system. The development of the control function descriptors for the six ATC systems is described in Section III of this report; Appendixes A through F contain additional operational details for each system.

2. Human Factors Descriptions

Seventeen factors were identified to describe pertinent performance capabilities and limitations of human controllers. These factors address job satisfaction and motivation, man-machine interface, and failure mode operations.* The factors were developed with the aid of project staff psychologists using previous studies for reference and guidance.[17-22] Each of the 17 factors was defined in terms of the degree to which a job situation is conducive to effective human performance. These factors are listed in Section IV of this report and described in detail in Appendix G.

3. Rating Mechanism

Project staff devised the rating forms (scoring questionnaires) with which system operations were evaluated. One form was designed for each system in such a way that 30 control functions could be quantitatively rated relative to the 17 factors. The critical factor and function pair comparison mechanism is conceptually illustrated in Figure 1.

The forms were filled out by 20 respondents, each of whom was a staff member from FAA headquarters, the National Aviation Facilities Experimental Center (NAFEC), or the Transportation Systems Center (TSC). The respondents were given instructions, rating guidelines for each factor, control function descriptions for each ATC system alternative, and the rating forms and were asked to rate numerically (on a scale of 1 to 5) certain functions against specified factors. This format was designed to solicit the respondent's judgment of the degree to which a control function contributes to desirable or undesirable aspects of human performance.

Section IV of this report includes a brief summary of the rating procedure (described in detail in Appendix H) and presents an overview of the rating data results (tabulated in Appendix I).

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*Failure mode is the means by which an ATC system operates when one or more components do not function such that the controller must compensate for the functional failure.

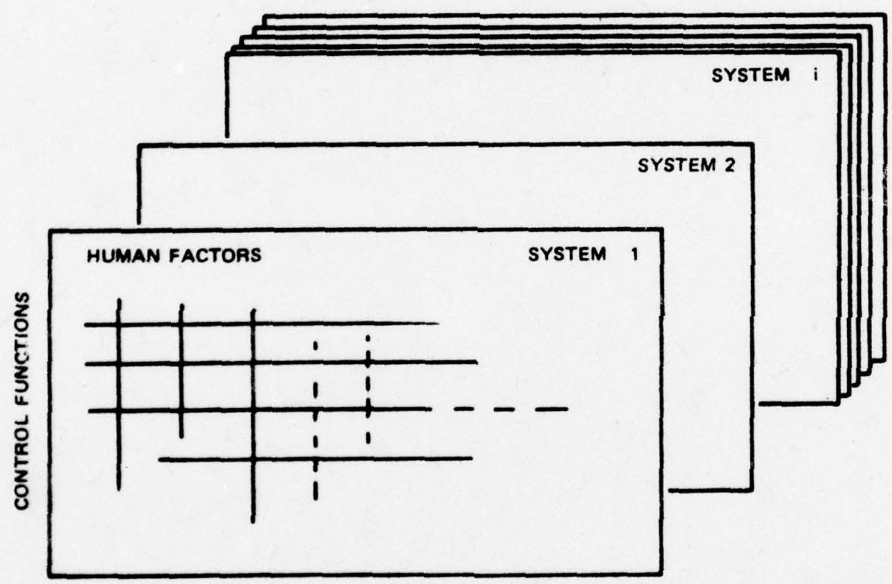


FIGURE 1 FACTOR AND FUNCTION PAIR COMPARISON FORMAT

4. <u>Rating Data, Analysis, and Conclusions</u>

SRI used computer data processing to compile, aggregate, and organize the rating data; identify rater biases; and develop rating statistics for analysis. The analysis identified those factors, functions, or factor and function pairs that were judged by the respondents to be the most critical items of future automation development. The current ATC operation was included in this rating exercise to provide a comparative basis for analyzing critical items and criticality trends for progressively higher levels of automation.

Section V of this report includes descriptions of the data analysis; conclusions developed from the analysis are presented in Section VI.

II ATC TECHNOLOGY

This section reviews the technologies leading to and including control-by-exception automation. The specific technological components considered are the items included as part of the FAA's Upgraded Third Generation Automation (UG3RD) program (see Table 1). The UG3RD program represents the current plans for future ATC technological development and is subject to revision as more information is obtained concerning automation potentials and need. However, the UG3RD technological components are representative of the levels of automation likely to be available in the future and are therefore useful for analyzing the impact of future automation on sector controllers.

The data link and control message automation components in Table 1 are the technological bases for control-by-exception systems operations. The intermediate components are potential predecessors to a control-by-exception system in that they could, in theory, be implemented before control-by-exception, assuming an evolutionary program for technological development. However, it is possible that some components, such as metering and spacing (M&S), may not precede control-by-exception but rather be incorporated into the control message automation logic.

A. Technological Component Descriptions

To develop a conceptual perspective on the operational implications of the various technological components listed in Table 1, the operational potentials of these components are described below. The descriptions are based on part on available descriptions of each component [1-3] and in part on observations of ATC operations.[8-12]

1. Current Technology

a. NAS/ARTS

The current enroute NAS Stage A and terminal ARTS III ATC operations include air/ground (A/G) and interphone voice communications; automated flight data processing and forwarding; air traffic control radar beacon system (ATCRBS); automatic tracking displays with alphanumerics (including Mode C and reported altitudes and ground speed); automatic and manual display filters; surveillance data mosaicing (enroute only); simplified clearance/coordination procedures; conflict alert; minimum safe altitude warning (MSAW); and central flow control. The ARTS III system directly supports terminal radar approach control (TRACON) operations; the alphanumeric display features are available in various airport tower cabs.

Table 1

AUTOMATION TECHNOLOGY

Automation Level	Technological Component
Current	NAS/ARTS; conflict alert Minimum safe altitude warning (MSAW)
Intermediate	Airport surface traffic control (ASTC) Wind shear advisory Wake vortex avoidance system (WVAS) Automated data handling (ADH) Microwave landing system (MLS) Area navigation (RNAV) Conflict probe Metering and spacing (M&S) Enroute metering Automated local flow control (LFC) Automated central flow control (CFC)
Advanced	Control message automation (CMA) Data link Discrete address beacon system (DABS) Automatic traffic advisory and resolution system (ATARS)

Sector operations in enroute centers and in TRACONs focus on the radar (R) controller. This critical decision maker performs the separation assurance and flight path management activities and may be supported by other controllers. Control task activities include A/G voice communications (R controller only); flight strip processing manual operations; intersector (including interfacility) interphone voice communications (R controller only); computer data entry and display manual processing; and intrasector direct voice consultations. Surveillance of plan view display (PVD) aircraft situation, identity, and related alphanumeric data enables controller flight-following. Controllers mentally project flight trajectories to detect and assess potential conflicts and resolve these conflicts by issuing clearances using A/G communications. Traffic flow organization and structuring are conducted in accordance with established procedural rules, which may be adjusted when local flow control operations are instituted.

Local, ground, and related control operations in towers use aircraft situation data obtained by direct observation and voice communications. Radar displays support situation surveillance operations.

b. Conflict Alert

Conflict alert detects minimum separation violations just prior to their occurrence and accordingly warns the controller (suggested resolutions are not included). Since this device operates on imminent potential conflict situations that occasionally may be "missed" by the controllers, it does not have an impact on controller thought processes that ordinarily occur. The conflict alert is a very useful safety enhancement that supplements the fundamental thought processes of controller decision making.

c. Minimum Safe Altitude Warning (MSAW)

MSAW automatically advises sector controllers of an aircraft flying or projected to fly below safe altitude limits. MSAW is a very useful safety enhancement that supplements the basic controller decision-making logic.

2. Intermediate Technology

a. Airport Surface Traffic Control (ASTC)

ASTC will introduce advanced surveillance display capabilities to the tower controller. Current plans call for implementing ASTC at some major airports. Although this feature will facilitate controller surveillance and reduce communication workload, basic decision-making logic will not be changed by ASTC implementation.

b. Wind Shear Advisory

Wind shear advisory will use ground sensors and computerized algorithms to identify dangerous wind shear situations in the vicinity of runways (especially approaches) and to advise local and approach controllers accordingly. The wind shear advisory is a very useful safety enhancement but is not expected to alter controller decision-making logic.

c. Wake Vortex Avoidance System (WVAS)

WVAS will detect or predict conditions of wake vortices behind large and/or heavy aircraft during low speed on final approach or departure. Resulting safety improvements and possible reduced aircraft separation requirements should increase runway capacities. The impact of WVAS on controller decision-making logic will depend on whether manual or automated systems are implemented. Manual WVAS will advise local and approach controllers of wake vortex existence but inherently will not affect controller decision-making logic. Automated WVAS will recommend specific spacing rules for a given aircraft pair that must be assimilated by the controller into his thought process. The assimilation by the controller of externally generated, dynamically changing, separation rules represents a departure from the current mode of operation and could require adjustments to the controller decision-making logic. (The questions of how and to what degree such adjustments would be made are beyond the scope of this study and are topics for further research.)

d. Automated Data Handling (ADH)

ADH includes the implementation of enroute and terminal sector control positions of an electronic tabular flight data display subsystem (ETABS) and a terminal information processing system (TIPS). The tabular display, an electronic flight data presentation designed to replace paper flight strips and attendant manual activities, automates flight data distribution between sectors and facilities. With inclusion of touch entry data processing, the resulting reduction in control workload per aircraft would increase sector traffic-handling capabilities. The tabular display with touch entry capabilities would facilitate information processing by the controller but is not expected to alter controller decision-making logic.

e. Microwave Landing System (MLS)

MLS is intended to upgrade the landing service of the current instrument landing system (ILS) by providing multiple-glide slope and curved approach capabilities. These capabilities may lower site preparation cost, allow MLS installation at sites where ILS is not practical, and reduce ground noise, but they will have no impact on the basic controller decision-making logic (i.e., the current thought processes would

still be required to control landing aircraft, although there may be a greater selection of approach paths).

f. Area Navigation (RNAV)

RNAV avionics and ATC interface automation could be used to achieve direct routing and closely spaced multilane traffic routes. The frequency of occurrence of potential conflict situations could be reduced by placing successive aircraft on the closely spaced parallel routes; hence, sector controllers could be relieved of some conflict resolution work. However, alterations to the basic decision-making logic are not envisioned (i.e., the current thought processes would still be required to move traffic and resolve conflicts, although there may be fewer conflict situations).

g. Conflict Probe

Conflict probe advises sector controllers of potential conflict situations and recommends resolution actions but operates over a significantly longer prediction horizon than the conflict alert. To provide an operationally realistic time prediction horizon, we assume this feature will be used when aircraft enter a sector. Workload reductions would reduce the conflict detection and assessment control task activity; A/G communications would still be required to transmit resolution instructions. Because a controller would need to assimilate the conflict probe's assessment and resolution recommendations into his thought processes, changes in current controller decision-making logic will be necessary. (The questions of how and to what degree such changes in logic would be made are topics for further research.)

h. Metering and Spacing (M&S)

M&S is a terminal ATC device designed to maximize airport runway use through precise control of interarrival times at runway thresholds. Suggested control instructions on aircraft headings, speeds, and altitude would be issued to TRACON controllers by the computerized metering and sequencing operation. Some workload reductions might be realized because of the reduction in controller decision times needed to assess and determine aircraft sequence assignment and the reduction of potential conflicts along inbound flight paths. However, the process by which the controllers assimilate the M&S recommendations into their thought processes implies a need for sector controllers to adjust their current decision-making logic. (The method and degree of such adjustment are topics for further research.)

Current UG3RD program concepts define three levels of M&S--basic, refined, and advanced. Basic M&S operates on airport arrival traffic; refined M&S extends basic M&S by including departures and multiple airports in complex terminal areas. For the purposes of this research,

basic M&S will not be considered since it is a part of refined M&S. Advanced M&S incorporates data link communications, which we treat as part of control-by-exception automation.

i. Enroute Metering

Enroute metering, an extension of terminal M&S, would require enroute controllers to set up aircraft spacings in accordance with time-varying terminal metering specifications. Sector controllers would need to respond to flow control procedural restrictions in much the same fashion as they now respond, but facility flow controllers would need to adjust their current decision-making logic to conform to the enroute metering operation. (The method and degree of such adjustment are topics for further research.)

j. Automated Local Flow Control (LFC)

Automated LFC is designed to maximize utilization of sector capacity by smoothing out traffic peaking situations. It would govern traffic flow on routes by means of an on-line computerized traffic planning process that regulates workload surges in accordance with the traffic-handling capabilities of a multisector environment. By constraining traffic peaks and their concurrent workload surges, LFC may be capable of regulating congestion and alleviating delays. As in the case of enroute metering, sector controllers would need to respond to flow control procedural restrictions in much the same fashion as they now respond, but facility flow controllers would need to adjust their current decision-making logic to conform to the local flow control operation. (The method and degree of such adjustment are topics for further research.)

k. Central Flow Control (CFC)

Automation will introduce a dynamic on-line data update capability into current CFC and related operations. The resulting improvement in traffic demand estimation for major terminals and along major corridors would support the other terminal and enroute flow metering and management components and possibly affect decision-making logic at the facility flow controller level. (The method and degree of impact are topics for further research.)

3. Advanced Technology

a. Control Message Automation (CMA)

CMA components are the bases of the control-by-exception operation where the controller would become a system manager who is not routinely engaged in all aspects of minute-by-minute tactical decision making but

rather responds to specific situations of interest. The computerized CMA operation will transmit to pilots such digital data as clearances and conflict avoidance directives. These transmissions would be compatible with the enroute and terminal metering and flow management operations.

A controller may interface with CMA in several ways--for example, (1) he may review and critically assess specific clearances and advisories recommended by the computer operation; (2) he may review and critically assess only the control strategies being used by the computer operation; or (3) he may concentrate on maintaining and updating the CMA data base and not perform any review and critical assessment of operations. Considerable adjustments need to be made to the controller decision-making logic to conform to the CMA operation. (The method and degree of such adjustments are topics for further research.)

b. Data Link

Clearances and advisories generated by the CMA operation will be transmitted to aircraft digitally, rather than through voice communication by controllers.

c. Discrete Address Beacon System (DABS)

DABS surveillance, as an alternative to current ATCRBS, is intended to provide high-reliability, high-accuracy, and high-capacity aircraft situation data acquisition capabilities necessary to support control-by-exception automation. Data link capability is inherent in the DABS design and is an alternative to independent VHF/UHF data link.

d. Automatic Traffic Advisory and Resolution Service (ATARS)

ATARS provides traffic advisories and threat avoidance commands to pilots as needed. Since this service could operate on out-of-the-ordinary imminent conflict situations, it is analogous to the conflict alert except that commands are transmitted by means of data link. ATARS would serve as a back-up to an advanced ATC system.[1]

B. Alternative Technological Configurations

As a first step toward defining system configurations, the technological components described in Section II.A were classified according to the type of automation service they provide and their operational application (see Table 2). Information aids are those components that enhance the quality or quantity of the information used by controllers or facilitate data processing without necessarily changing the character of a controller's thought processes (i.e., decision-making logic). Decision

Table 2

AUTOMATION APPLICATIONS

Automation Service	Operational Application: Sector Traffic Control	Operational Application: Facility Flow Control
Information aids	Airport surface traffic control (ASTC) Wind shear advisory Manual wake vortex avoidance system (WVAS) Automated data handling (ADH) Microwave landing system (MLS) Area navigation (RNAV) Discrete address beacon system (DBAS) surveillance	
Decision aids	Conflict probe Automated WVAS Refined metering and spacing (M&S)	Enroute metering Automated local flow control (LFC) Automated central flow control (CFC)
Decision automation	Control message automation (CMA) Data link Automatic traffic advisory and resolution system (ATARS)	

aids begin to affect a controller's thought processes by recommending decisions or conclusions. Decision automation enables controllers to remove themselves to varying degrees from the decision-making logic and therefore is the technological genesis of control-by-exception operations.

Although the classification of technological components in Table 2 is a useful first step toward defining system configurations, further consideration of operational requirements is necessary. For example, information aids, as a group, may be defined as one configuration, but this configuration is not of major interest to this research because operational processes would not change significantly (other than controller manual dexterity needs for operating with touch entry data processing rather than keyboards and flight strips). Major impacts of information aids on personnel characteristics and qualifications requirements are not foreseen; therefore, information aid automation will not be examined as an independent system configuration.

Decision aids are applicable to two operations: enroute and terminal ATC. The enroute configuration would consist of the conflict probe, enroute metering, LFC and CFC, and predecessor enroute information aid automation. The terminal configuration would consist of refined M&S, automated WVAS, CFC, and the predecessor terminal information aid automation.

The decision automation components--CMA, data link, and ATARS--are common to both enroute and terminal environments, but various strategies may be conceived to use these components in a control-by-exception system.

As a result of the above observations, and with the aim of further developing alternative ATC system concepts, the following technological configurations have been devised (see Table 3):

- NAS/ARTS
- Enroute decision aid automation
- Terminal decision aid automation
- Control-by-exception.

Note that these configurations are defined for the purposes of this research. They are intended as investigative demonstrations of the different ways in which automation might be implemented and are not meant to represent FAA-specified configuration designs. For the purposes of this study, implementation of the components is assumed, but the timing and extent of implementation have not been determined.

Table 3

ALTERNATIVE AIR TRAFFIC CONTROL
SYSTEM CONFIGURATIONS

Configuration	Technological Component
NAS/ARTS	NAS Stage A ARTS III Conflict alert Minimum safe altitude warning (MSAW)
Enroute decision aid automation	NAS + Information aids + Conflict probe + Enroute metering + Automated local flow control (LFC) + Automated central flow control (CFC)
Terminal decision aid automation	ARTS + Information aids + Refined metering and spacing (M&S) + Automated wake vortex avoidance system (WVAS) + Automated central flow control (CFC)
Control-by-exception	Enroute/terminal decision aid automation + Control message automation (CMA) + Data link + Automatic traffic advisory and resolution service (ATARS)

III HUMAN CONTROLLER AND AUTOMATION ROLES

In this section a description of the sector ATC operation is developed and the roles played by human operators and computer for current and future technological configurations are postulated.

A. Sector Control Processes

The sector ATC operation is primarily concerned with servicing separation assurance requirements and secondarily with servicing the expeditious movement of aircraft along their respective flight paths. The sector control operation can be described as a set of logic processes that are followed by controllers in order to carry out their decision-making functions. The operation is structured into a set of procedures, operation rules, and responsibility assignments to provide the flight services. Based in part on observations of FAA control facility operations and in part on the analytical requirements of this research, the basic processes of sector control were conceptualized as follows (see Figure 2):

- Sector traffic flow planning
- Aircraft flight path planning
- Separation assurance decision making
- Flight information decision making
- Control message transmission.

1. Sector Traffic Flow Planning

Sector traffic flow planning is the process by which the overall procedural plan for organizing and moving traffic through a terminal or enroute sector is defined. The sector traffic flow plan is a specification of the preferred routing and associated altitude, speed, and spacing restrictions required within the sector and at sector boundaries. The sector traffic flow plan is set up in response to changes in the circumstances under which the sector is to operate and, as such, conforms to constraints imposed by sector ATC equipment operating status (e.g., VOR outage, runway closure); weather status (e.g., wind direction, frontal activity, turbulance); traffic congestion; and external procedural constraints (i.e., flow control route restrictions, or altitude, speed, and in-trail spacing restrictions at sector exit boundaries). A sector traffic flow plan designed to satisfy the above changes may prescribe route diversions around weather front activity, tunneling routes under other congested routes, a revised airport approach and departure plan

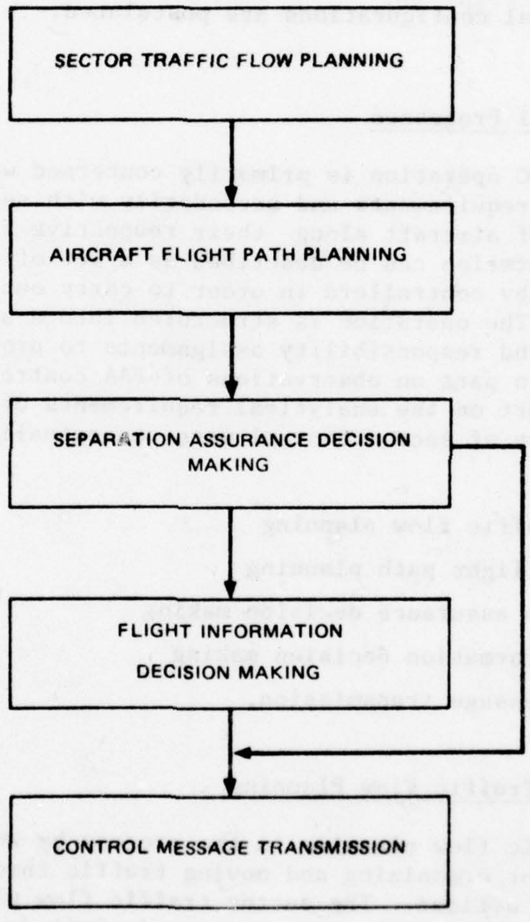


FIGURE 2 SECTOR AIR TRAFFIC CONTROL PROCESSES

for a new wind direction, or altitude and speed controls for facility flow control. A sector traffic flow plan established for one sector may impose procedural constraints on an adjacent sector; that is, a sector traffic flow plan may include altitude and speed controls on incoming aircraft at sector entry boundaries that must be observed by the upstream sectors.

2. Aircraft Flight Path Planning

Aircraft flight path planning is the process by which the flight trajectory intentions for aircraft coming into a sector are finalized and made to conform with the sector traffic flow plan. The flight path plan may coincide with the computer-filed flight plan (as requested by the pilot or as cleared through upstream control sectors) or as a modification to the computer-filed flight plan. Such modifications are made to fit the aircraft into the current sector traffic flow plan. For example, routing and procedural restrictions associated with route diversions around weather front activity, tunneling under congested routes, reversed airport approach and departure operations for a new wind direction, or altitude and speed controls for flow control may be in conflict with the computer-filed flight plan. In such cases, a new flight path plan is defined which preempts the filed plan but meets the route, altitude, and speed restrictions of the sector traffic flow plan.

The sector traffic flow and aircraft flight path planning processes provide preliminary, or first-cut, separation services in that they preclude the development of untenable traffic congestion situations. The implementation of altitude and speed restrictions often serves to procedurally separate flows of traffic and thereby prevents subsequent congestion situations where minute-by-minute separation of individual aircraft would be extremely difficult.

3. Separation Assurance Decision Making

Separation assurance decision making is the process by which individual aircraft are kept free of conflicts with other aircraft. The tracks and projected trajectories of aircraft are monitored to detect potential future pairwise violations of separation rules between aircraft. The process operates by following individual aircraft on a continual basis rather than by monitoring aggregate traffic flows and congestion situations. The intention is to guarantee the safe movement of the aircraft along the next segment of its flight trajectory by clearing the aircraft from point to point along its flight path plan. Where a pairwise separation violation is projected, a flight path modification is necessary to resolve the potential conflict situation. The conflict resolution action may be tactical--whereby flight trajectories are time separated by precisely controlling vectoring, speed, or altitude maneuvers--or procedural--whereby flight paths are spatially separated by assigning nonintersecting routes or altitudes. The separation assurance

decision-making process results in the selection of specific clearances and advisories for subsequent transmission to aircraft.

4. Flight Information Decision Making

Flight information decision making is the process by which the data needs of individual aircraft are served after separation assurance is performed. This process identifies control requirements that have not been satisfied by the separation assurance process for routinely moving aircraft along conflict-free flight segments (i.e., where potential conflicts are not in existence) and for the issuance of additional instructional or advisory information (e.g., A/G frequency change, weather data, airport operational situation, navigational instruction). The flight information decision-making process results in the selection of specific clearances and advisories for subsequent transmission to aircraft.

5. Control Message Transmission

Control message transmission is the process by which specific clearances and advisories are issued to aircraft and pilot responses are received.

The sector control processes described above are simplifications of real-world sector control operations, and they segregate certain control actions that are actually performed in an integrated manner. However, the processes were defined so that their descriptions not only include and represent the primary operational requirements of sector traffic control but also are amenable to subsequent analyses of automation impact. In particular, each control process definition lends itself to the formulation of system descriptions that distinguish the operational activities of the human controller and the computer.

B. Alternative Systems Operations

On the basis of the control process definitions presented above and the technological configurations developed in Section II, the following alternative systems of sector control operations were defined:

- System 1: NAS/ARTS
- System 2: Enroute Decision Aid Automation
- System 3: Terminal Decision Aid Automation
- System 4: Control-by-Exception (Level I)
- System 5: Control-by-Exception (Level II)
- System 6: Control-by-Exception (Level III).

These systems were developed by specifying plausible control process responsibilities for the human controllers for each technological configuration and by considering alternative means of using the control-by-exception technology. We describe below the primary role of the controller in the control processes for each system. Table 4 summarizes these roles and shows an evolution of increasing levels of automation sophistication and responsibility beginning with the NAS/ARTS system.

NAS/ARTS--The controller performs the decision-making requirements of each control process (except for the automated conflict alert and MSAW searches for emergencies).

Enroute Decision Aid Automation--The controller continues as the primary operational planner but calls on the conflict probe to search and assess potential conflicts.

Terminal Decision Aid Automation--The controller critically reviews sector traffic flow plans, aircraft flight path plans, and separation assurance and flight information clearances and advisories recommended by the computer operation (in which M&S is the dominant automation technology). The controller issues all clearance and advisories by means of voice A/G radio communications.

Control-by-Exception (Level I)--The controller critically reviews sector traffic flow planning, aircraft flight path planning, and separation assurance clearances and advisories recommended by the control message transmission. In this process, the controller's attention is centered on planning operations and on the details of the critical separation assurance activities; he does not critically assess the computerized flight information decision-making process. Clearance and advisories are issued by data link, except for those few messages requiring voice relay by the human (e.g., communications with non-data-link aircraft).

Control-by-Exception (Level II)--The controller reviews (without critical assessment) and accepts the computer-recommended sector traffic flow and aircraft flight path plans (i.e., he maintains cognizance of the planning operations without directing them). The controller critically reviews the strategies recommended by the control message transmission; he does not review and assess the specific clearance and advisories associated with automated separation assurance and flight information decision making. His attention is concentrated on the critical separation assurance events, although the detailed control message requirements are not evaluated. Clearances and advisories are issued by data link, except for those few messages requiring voice relay.

Table 4

OVERVIEW OF HUMAN CONTROLLER ROLES IN ALTERNATIVE AIR TRAFFIC CONTROL SYSTEMS

Control Process	NAS/ARTS	Enroute Decision Aid Automation	Terminal Decision Aid Automation	Control-by-Exception (Level I)	Control-by-Exception (Level II)	Control-by-Exception (Level III)
Sector Traffic Flow Planning	Define sector traffic flow plan	Define sector traffic flow plan	Critically review sector traffic flow plan	Critically review sector traffic flow plan	Maintain cognizance of sector traffic flow plan	Input miscellaneous data for sector flow planning
Aircraft Flight Path Planning	Define aircraft flight path plan	Define aircraft flight path plan	Critically review aircraft flight path plan	Critically review aircraft flight path plan	Maintain cognizance of aircraft flight path plan	*
Separation Assurance Decision Making	Define conflict resolution clearances and advisories	Critically review conflict resolution clearances and advisories	Critically review conflict resolution clearances and advisories	Critically review conflict resolution clearances and advisories	Critically review conflict resolution strategy	Input miscellaneous data regarding aircraft flight path
Flight Information Decision Making	Define other clearances and advisories	Define other clearances and advisories	Critically review other clearances and advisories	*	*	*
Control Message Transmission	Issue A/G voice message	Issue A/G voice message	Issue A/G voice message	Maintain cognizance of data-link message and relay miscellaneous A/G voice message	Relay miscellaneous A/G voice message	Relay miscellaneous A/G voice message

*No human controller involvement.

Control-by-Exception (Level III)--The controller is removed from all review and assessment operations. He processes data not otherwise accessible by the computer operation, monitors conflict alerts, and occasionally relays voice messages when appropriate.

C. Control Functions

Each control process was described at a level of detail that allowed an analysis of the specific items of compatibility between the human controller and the computer. Thus, each process was divided into component subprocesses called "control functions," which are sets of control actions that may be performed by the controller or the computer, depending on the specific technological configuration under consideration. Table 5 presents the control functions and their allocations for each of the six alternative systems.

The control processes and functions for each system are described in detail in Appendixes A through F. It is recommended that the reader review the appended material to appreciate the underlying thought processes, manual activities, and data transfer transactions required by the controller and the computer for each system. The material in Appendixes A through F was given to the raters as part of the system descriptions used for human factors assessment. The raters were also given more detailed descriptions of each control function. These descriptions, which are not included in this report, parallel the control function summaries included in Appendixes A through F.

Table 5
CONTROL FUNCTION ALLOCATIONS

Control Process	Control Function	Control Function Responsibility by ATC System*					
		NAS/ARTS	Decision Aid Automation		Control-by-Exception Automation		
			Enroute	Terminal	I	II	III
Sector Traffic Flow Planning	1. Monitor changes to the sector operating status	M	M	M	M	M	M
	2. Establish automated processing of a sector traffic flow plan			M	M	M	M
	3. Determine a sector traffic flow plan	M	M	A	A	A	A
	4. Review the computer-recommended sector traffic flow plan			M	M	M	
	5. Revise the computer-recommended sector traffic flow plan			M	M		
	6. Issue the sector traffic flow plan	M	M	A	A	A	A
Aircraft Flight Path Planning	7. Monitor changes to the traffic flight plans	M	M				
	8. Determine a flight path plan for an aircraft	M	M	A	A	A	A
	9. Review the computer-recommended flight path plan			M	M	M	
	10. Revise the computer-recommended flight path plan			M	M		
Separation Assurance Decision Making	11. Monitor the routinely changing air traffic situation	M	M	A	A	A	A
	12. Monitor only routinely changing air traffic situations reported by pilots			M	M	M	M
	13. Establish an automated processing of control intervention actions		M	M	M	M	M
	14. Search for a potential control intervention action	M					
	15. Search for an imminent (emergency) conflict situation †	A	A	A	A	A	A
	16. Monitor a computer report of an imminent (emergency) conflict situation†	M	M	M	M	M	M
	17. Confirm the existence or nonexistence of a potential conflict	M					
	18. Determine a strategy to resolve the potential conflict	M	A	A	A	A	A
	19. Determine specific clearances and advisories to resolve the potential conflict	M					
	20. Review the computer assessment and recommended resolution of a potential conflict		M	M	M	M	
	21. Revise the computer recommended strategy, clearances, and advisories to resolve the potential conflict		M	M	M		
	22. Revise only the computer recommended strategy to resolve the potential conflict					M	
Flight Information Decision Making	23. Search for a flight information service action (other than separation services)	M	M	A	A	A	A
	24. Determine specific clearances and advisories to provide flight information service	M	M				
	25. Review the computer-recommended action for flight information service			M			
	26. Determine advisories to supplement the computer recommended clearances			M			
	27. Revise the computer-recommended flight information service action			M			
Control Message Transmission	28. Issue clearances and advisories	M	M	M	A	A	A
	29. Review computer transacted clearances and advisories				M		
	30. Relay clearances and advisories				M	M	M

*M indicates man or woman (i.e., function performed by human); A indicates automation (i.e., function performed by computer).

†Functions 15 and 16 pertain to interruptions to routine control activities by the conflict alert, automatic traffic advisory and resolution service (ATARS), and minimum safe altitude warning (MSAW) automation.

IV RATING DATA

In order to rate the alternative ATC systems and control process functions, 17 factors were identified in the areas of job satisfaction and motivation, man-machine interface, and failure mode operations (see below). Human factors psychologists and personnel specialists participated in defining these factors and in designing a scoring metric. In addition, previous work in the field of general and controller human factors was used for reference.[17-22]

Job Satisfaction and Motivation

1. Achievement--work alignment
2. Recognition
3. Responsibility
4. Control authority
5. Utilization of perceived skills
6. Challenge--discretionary flexibility
7. Performance feedback
8. Interest

Man-Machine Interface

9. Vigilance
10. Stress
11. Intricacy
12. Restrictiveness
13. Rigidity
14. Decision making

Failure Mode Operations

15. Failure recognition
16. Failure recovery
17. Failure operations

A host of job satisfaction and motivation factors in addition to those listed above are relevant to the general study of the impacts of automation on human controllers. Such factors as opportunity for advancement, interpersonal relations with peers and supervisors, working conditions, personal life, and salary were not included because the complexity of the analysis required was beyond the scope of this preliminary research into human factors issues.

A. Rating Procedure

The 20 raters were given a rating form for each system and were instructed to score selected control functions relative to particular factors as specified on the forms. The scoring was made using an integer rating scale, or metric, ranging from 1 to 5. The lowest rating value, 1, represents the least desirable job environment; the highest rating value, 5, represents the most desirable job environment. The factors and rating procedures are described in Appendix G; sample rating forms for each system are included in Appendix H.

B. Rating Data Results

The rating scores were processed by computer to obtain the average responses of the sample set of raters. The resulting human factors average ratings for each function of each system are summarized in Appendix I. These raw data were further processed to account for individual biases when some raters responded consistently with very high or low scores while others did not. The average ratings were adjusted to remove the effects of individual biases, and the unbiased average ratings presented in the graphs in Figures 3, 4, and 5 were obtained. A mathematical statement of the bias adjustment calculations is included in Appendix J.

The graphs in Figures 3, 4, and 5 show the perceptions of the raters in regard to human factors as automation increases. (Recall that increases in ratings represent increasingly desirable job environments.) The average ratings for job satisfaction and motivation (Figure 3) are generally highest for System 1 (NAS/ARTS) and usually decrease as each succeeding system is examined. Conversely, the ratings for man-machine interface (Figure 4) are lowest for System 1 (for all factors except factor 11) and generally constant or higher for each succeeding system. The ratings for failure mode operations (Figure 5) show less consistent trends.

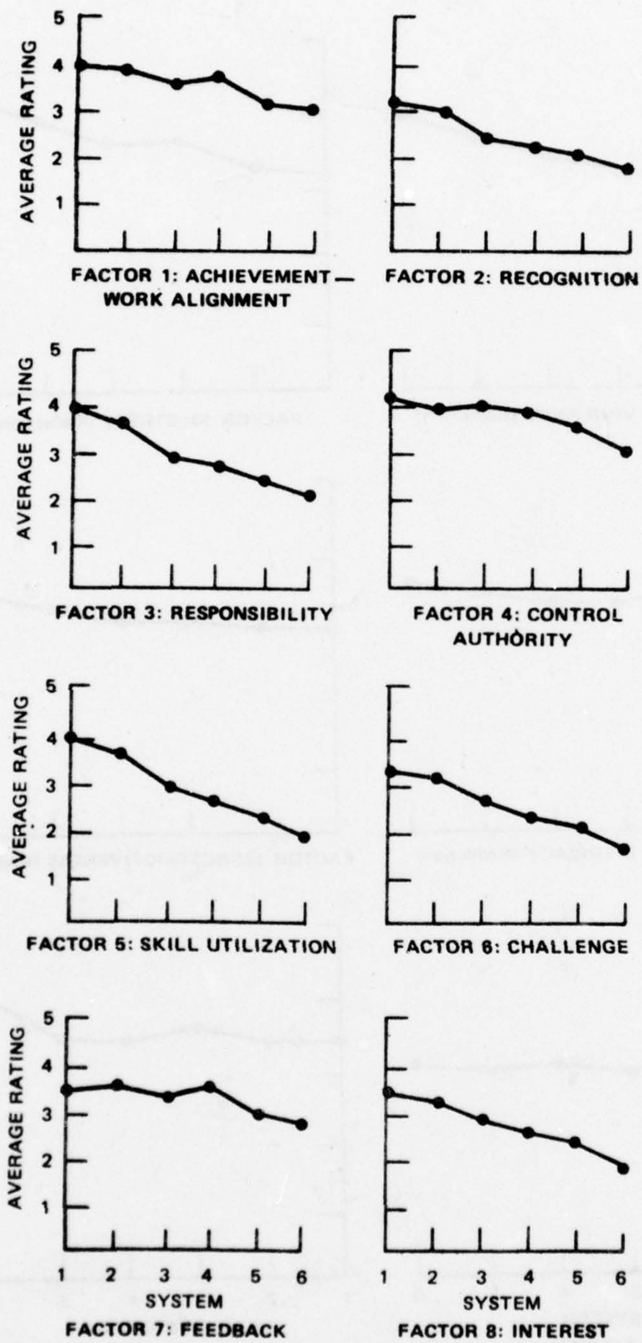


FIGURE 3 ADJUSTED AVERAGE RATINGS FOR EACH ATC SYSTEM: JOB SATISFACTION AND MOTIVATION

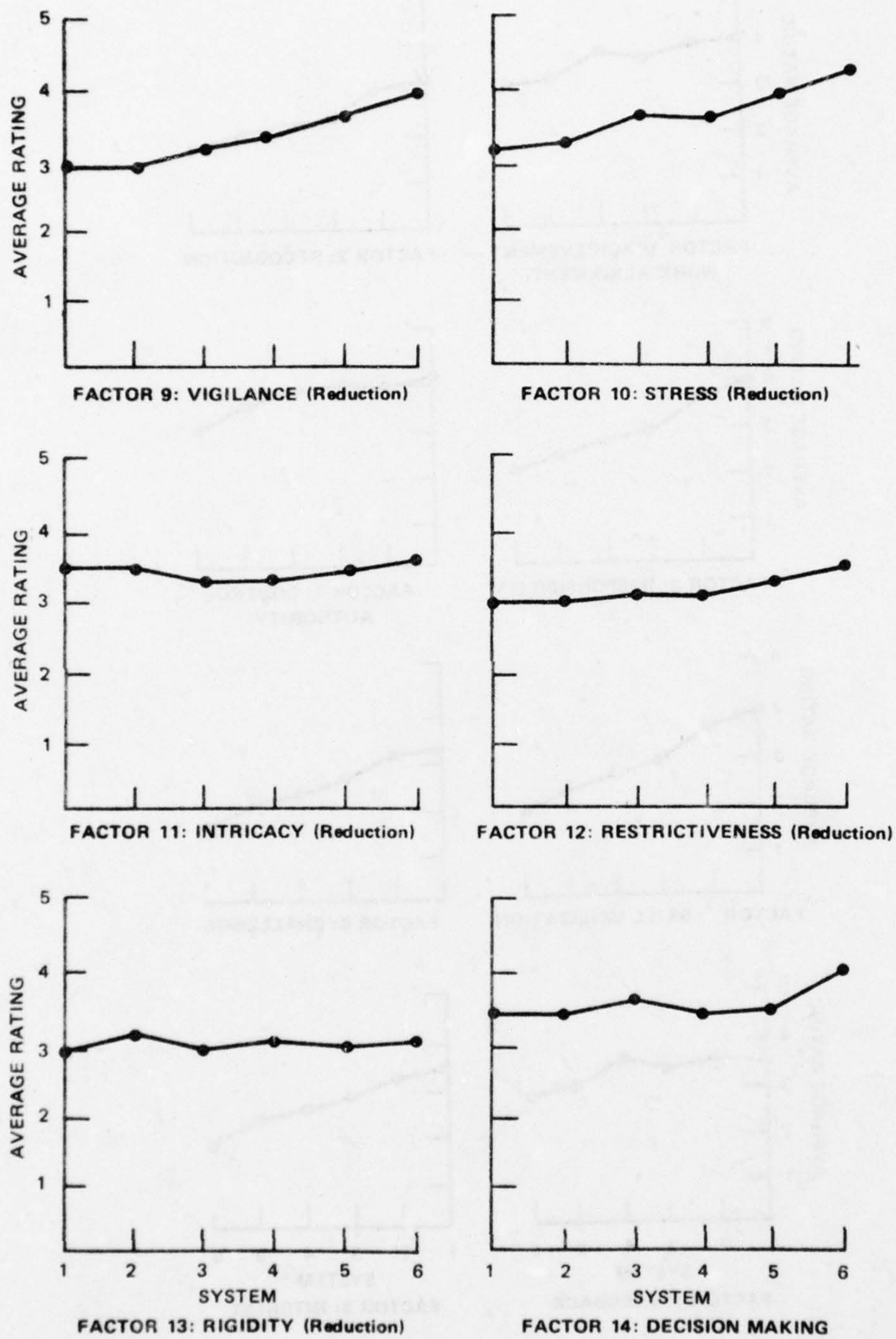
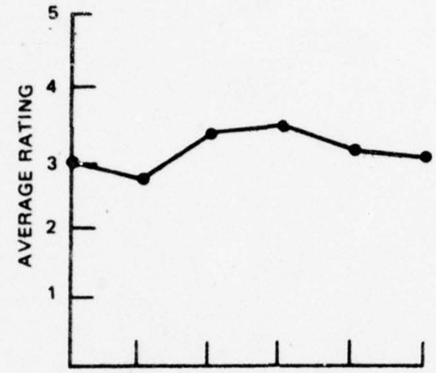
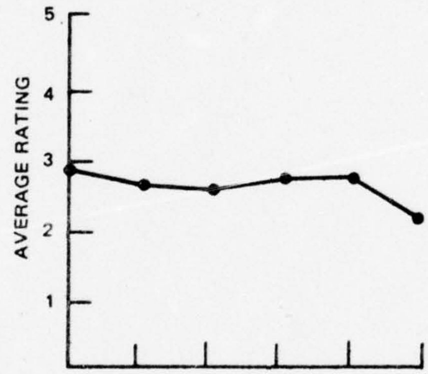


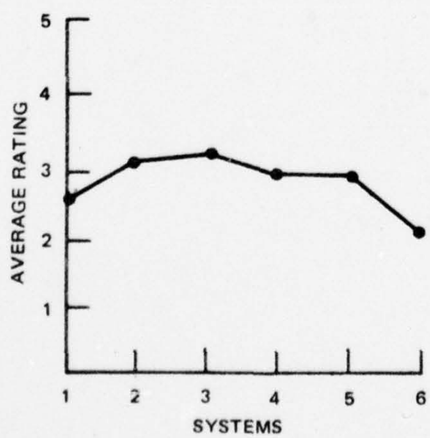
FIGURE 4 ADJUSTED AVERAGE RATINGS FOR EACH ATC SYSTEM: MAN-MACHINE INTERFACE



FACTOR 15: FAILURE RECOGNITION



FACTOR 16: FAILURE RECOVERY



FACTOR 17: FAILURE OPERATIONS

FIGURE 5 ADJUSTED AVERAGE RATINGS FOR EACH ATC SYSTEM: FAILURE MODE OPERATIONS

V DATA ANALYSIS

The approach selected to analyze the rating data involved comparing the five proposed future systems with the NAS/ARTS system. The ratings given to each control function were examined to identify critical factor and function pairs for each system. The significance of these pairs in terms of both the overall control process and the role of the controller in future systems was analyzed. The observations discussed below were derived from the analysis.

Some factors were rated similarly in all systems and therefore were judged to be "not significant" in terms of automation impact. Such factors include control authority, feedback, decision making, restrictiveness, intricacy, and rigidity.

The automation of a monitoring or decision-action function results in an immediate and significant reduction in the rating of certain job satisfaction and motivation factors--recognition, responsibility, skill utilization, challenge, and interest. This rating reduction is most often accompanied by a significant decrease in stress, as the controller relinquishes personal responsibility for the performance of a task to the computer.

In Systems 2 and 3 (Enroute and Terminal Decision Aid Automation) and System 4 (Control-by-Exception, Level I), the decision-action function is automated but the controller still performs a manual assessment function, such as reviewing and revising computer output, tactical clearances and advisories, or strategy. The reduction in ratings of job satisfaction and motivation factors caused by automating decision-action functions is compensated for by the relatively high ratings for the manual assessment functions In effect, the raters may be indicating that a controller would recei[illegible] as much satisfaction; feel as much challenge, interest, and responsibility; and use the same skills for reviewing and revising the computer as when he performed the original unautomated function The raters also considered the assessment function less stressful than the original monitoring or decision-action function, perhaps due to their perception of a computer as a vigilant, tireless monitor that is well equipped to apply logical rules to certain decisions.

For the separation assurance process, raters probably felt that the manual assessment function of revising a computer's recommended strategy and tactical decisions for avoiding conflict was almost as stressful as when a controller makes those decisions himself. However, in the area of job satisfaction and motivation, a controller derives a sense of responsibility, challenge, and interest from revising and reviewing the computer's decisions. A sense of recognition is gained from revising a computer's plans; recognition was not rated as high for reviewing a computer's plans.

The high ratings given to job satisfaction and motivation factors because of manual assessment functions are reduced as the revision task is eliminated in System 5 (Control-by-Exception, Level II) and the review task is eliminated in System 6 (Control-by-Exception, Level III).

The raters were concerned with equipment failure only in the highly critical separation process in System 6 where the controller may not be cognizant of the tactical traffic situation.

The remainder of this section reviews the procedures and analyses used to develop the above observations.

A. Identification of Critical Factor and Function Pairs

The control function composition of each system changes as successive levels of automation are developed (see Table 5). Using System 1 (NAS/ARTS) as a basis for comparison, each function of System 1 is either modified or eliminated as future systems with more automation evolve; in some cases, new functions not present in System 1 are added for the future systems. To identify meaningful impacts of the new systems on the 17 human factors, the adjusted (unbiased) average ratings for the function and factor pairs (derived from the raw data presented in Appendix I) were examined.

The pairwise factor-function ratings in System 1 were used as the baseline, and the maximum rating change of a factor and function pair between System 1 and any other system was identified--that is, the arithmetic difference between a system factor and function pair rating and a corresponding rating (if scored) for each of the other systems was calculated and the greatest absolute value of these differences was defined as the maximum rating change. The resultant maximum rating changes were found to be distributed bimodally; exactly half of the maximum rating changes were less than 1 in absolute value. This distribution was judged to be significant because a score change of 1 or more ensures that a rater's perception of the pair has shifted substantially--in fact to a different level on the rating scale. In addition, concentrating on the remaining critical pairs makes the analysis much more tractable (an important consideration when a great deal of data is being analyzed).

The factor and function pairs with maximum rating changes equal to or greater than 1 (relative to System 1 scores) were defined as critical. However, this criterion does not consider certain functions that are introduced into Systems 2 through 6 as automation is increased and whose ratings could not be arithmetically compared with those of System 1 because of a lack of correspondence in functional descriptions. In such cases, any new function that causes a rater to rate a factor very high or very low would be significant; those functions eliciting only ambivalent responses would not be. Therefore, a second criterion for criticality was defined: for any system other than System 1, a factor and function pair (that is not scored in System 1) is significant if its average rating is neither greater than 4 nor less than 2. (Recall that the rating scale ranges between 1 and 5.)

Figure 6 shows which factor and function pairs are significant by each criterion and identifies the system in which the pair first becomes critical. For example, function 3 (determine flow plan) was found to be critical relative to factor 2 (recognition) in System 4. The significance criterion in this case was a maximum rating change of at least 1.

B. Analysis of Critical Factor and Function Pairs

The analysis of critical factor and function pairs identified in Figure 6 addressed the operational implications of the critical pairs in the context of five control processes--sector traffic flow planning, aircraft flight path planning, separation assurance decision making, flight information decision making, and control message transmission. These operational interactions were examined to develop an understanding of the reasons why raters perceived certain factors and functions as critical.

The control process functions were grouped according to the operational roles assigned to the human controllers. The control functions listed in Table 5 were aggregated into one of three subprocesses: (1) monitoring; (2) taking action (or making a decision); and (3) assessing the results of a computer-generated plan or alarm. The first two subprocesses can be automated; the third is a by-product of automation and is found typically in Control-by-Exception, Levels I and II. The assessment process often replaces a monitoring or action task taken over by automation and thus serves as compensation to the controller.

1. Sector Traffic Flow Planning Process

In the sector traffic flow planning process, as it is implemented today (see Table 5), a controller monitors data describing changes to the sector equipment and weather status, procedural constraints imposed by other sector or flow controllers, and the aggregate traffic situation, and then defines and coordinates a sector traffic flow plan. Automation plays no part in the decision-making process. The control functions implemented in System 1 can be broken down into three control subprocesses: (1) the controller monitors status changes (monitoring); (2) determines a flow plan (decision-action); and (3) issues the flow plan (action). In System 3 (Terminal Decision Aid Automation), the computer reviews the sector operating status and defines and displays a sector traffic flow plan. Two action functions have been automated and taken away from the controller, but in return the controller performs two assessment functions: he reviews and revises the computer-recommended plan. As automation increases in Systems 5 and 6 (Control-by-Exception Levels II and III), these assessment functions are reduced and finally eliminated as the controller is no longer required to monitor the computer.

As indicated in Figure 6, the sector traffic flow planning process has two critical functions: determination of the traffic flow plan (action) and issuance of the flow plan (action). Beginning with System 3,

FUNCTION *

1. MONITOR SECTOR STATUS
2. ESTABLISH AUTOMATED FLOW PLAN
3. DETERMINE FLOW PLAN
4. REVIEW COMPUTER PLAN
5. REVISE COMPUTER PLAN
6. ISSUE FLOW PLAN
7. MONITOR FLOW PLAN
8. DETERMINE FLIGHT PLANS
9. REVIEW FLIGHT PLAN
10. REVISE COMPUTER PLAN
11. MONITOR COMPUTER PLAN
12. MONITOR ROUTINE ATC SITUATION
13. MONITOR PILOT REPORTS
14. ESTABLISH AUTOMATED PROCESSING
15. SEARCH FOR CONTROL ACTIONS
16. SEARCH FOR IMMINENT CONFLICT
17. MONITOR IMMINENT CONFLICT
18. CONFIRM POTENTIAL CONFLICT REPORT
19. DETERMINE CONFLICT
20. DETERMINE CONFLICT STRATEGY
21. DETERMINE SPECIFIC CLEARANCES
22. REVIEW COMPUTER RESOLUTION
23. REVISE COMPUTER RESOLUTION
24. REVISE COMPUTER STRATEGY
25. SEARCH FOR SERVICE ACTION
26. DETERMINE SPECIFIC ACTION
27. REVIEW COMPUTER CLEARANCES
28. DETERMINE COMPUTER INFORMATION
29. DETERMINE SUPPLEMENTARY INFORMATION
30. REVISE COMPUTER INFORMATION
31. ISSUE SUPPLEMENTARY ADVISORIES
32. ISSUE CLEARANCES
33. REVIEW COMPUTER CLEARANCES
34. RELAY CLEARANCES

FACTOR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1. Achievement						□5										□6				○2	○2									
2. Recognition			□4			□3	□5	□3			□4						□2	□2	□2		○2		□4	□3				□4		
3. Responsibility			□3			□3	□5	□3			□3		○2		□6	□5	□2	□2	□2	○2	○2	○6	□3	□3				□4		
4. Control authority													○3								○2									
5. Skill utilization			□3			□3	□3	□3			□3				□6	□6	□2	□2	□2	○2	○2		□3	□3				□4		
6. Challenge			□3			□3	□3	□3			□3				□5		□2	□2	□2	○2	○2		□3	□3				□4		
7. Feedback																					○2									
8. Interest			□3			□3	□6	□3			□6						□3	□2	□2	○2	○2		□4	□3				□4		
9. Vigilence							⬡3				⬡3												⬡3							
10. Stress			⬡3	○3		⬡3		⬡3			⬡3				⬡3	⬡6	⬡2	⬡2	⬡2					⬡3	○3	○3		⬡4		
11. Intricacy																														
12. Restrictiveness																														
13. Rigidity																														
14. Decision				○3							⬡6																			
15. Failure recognition															⬡6															
16. Failure recovery															⬡6															
17. Failure operations																														

□ Indicates a factor and function pair whose rating decreases by at least 1.0 from System 1

⬡ Indicates a factor and function pair whose rating increases by at least 1.0 from System 1

○ Indicates a factor and function pair whose rating is at least 4.0 (the function is not represented in System 1).

The number within each symbol represents the system number at which the criterion is first met.

*See Table 5 for complete descriptions of control functions.

FIGURE 6 CRITICAL FACTOR AND FUNCTION PAIRS

there is a significant reduction in rating for several job satisfaction and motivation factors: recognition, responsibility, skill utilization, challenge, and interest. Although the controller was given responsibility for two assessment functions, the raters felt that these tasks did not adequately compensate for tasks that were previously performed manually, as the ratings for the functions were about average. It can be concluded that the performance of the sector traffic flow planning process is regarded as a satisfying challenge. Substituting assessment functions for this process is not compensatory because the challenge has been preempted by the computer.

The stress associated with determining the sector traffic flow plan is seen to be reduced as automated equipment takes over the function. The substituted assessment function also received a significant rating indicating low stress. The tasks of reviewing and revising the computer's plan were not considered stressful because raters regard the computer as competent to perform this planning function. This observation is corroborated by the significant score given to the assessment function in decision making: raters regarded the review of a computer's flow plan as relatively easy (in fact, easier than reviewing a plan manually).

2. Aircraft Flight Path Planning

In the aircraft flight path planning process, either a controller or automation monitor change aircraft flight plans, tracks, and the traffic situation and define a flight path plan for each aircraft in the sector. This process is performed automatically in Systems 3 through 6 (Terminal Decision Aid Automation and all three levels of Control-by-Exception). In Systems 3 and 4 the controller reviews and can revise the computer-recommended flight path plan; in System 5 the controller reviews the plan without critical assessment; and in System 6 there is no human involvement in this process.

The aircraft flight path planning process fits the subprocess aggregation since it has a monitor function, decision-action function, and an assessment function (composed of the review and revise functions). Beginning with System 3, the assessment function is substituted for the monitoring and decision-action functions; in System 5, however, it becomes passive as the controller is expected only to review the computer-recommended flight path plan. The assessment function is taken away completely in System 6. The job satisfaction and motivation factors of recognition, responsibility, skill utilization, challenge, and interest are all rated significantly low for both the monitor and decision-action functions (see Figure 6). Interestingly enough, the monitor function is rated significantly lower in recognition only in System 5, where the controller is expected to review the computer-recommended flight plan to stay abreast of development but not to critically assess it. The controller's interest does not wane significantly until System 6 when he has no part whatever in the flight path planning process.

The amount of vigilance required to monitor changes in the traffic flight path plans is reduced significantly when that function is automated. Similarly, the amount of stress involved in determining a flight path plan for an individual aircraft is reduced when that function is automated in System 3. Substituting assessment functions for the monitoring and decision-action functions had no significant effect. The raters judged the assessment functions to be approximately average with respect to both job satisfaction and motivation and man-machine interface factors.

3. Separation Assurance Decision-Making Process

The separation assurance decision-making process is the most tactical of the control processes and includes some of the most important functions performed by the controller. In the current NAS/ARTS system, the controller monitors changing aircraft, track, and traffic situations; searches for control intervention situations; identifies potential conflicts; and defines and coordinates clearances and advisories to resolve conflicts. The controller also responds to computer alerts for emergency situations (conflict alert and MSAW). In System 2 and all higher-level automation systems, a conflict probe automatically identifies potential conflicts and recommends resolution actions. Beginning with System 3 the controller is not even required to monitor all routinely changing aircraft traffic situations; he is responsible, however, for reviewing and revising the computer's recommended resolution of a potential conflict. This assessment function is reduced in System 5 where the controller is required to modify the computer's strategy for resolving potential conflicts but not to review the details of clearance and advisory messages. By System 6 the controller's only role is to monitor the computer's report of an imminent emergency conflict situation. He has no active role and is required neither to determine specific clearances and strategies nor to revise a computer's plans. The controller only monitors pilot traffic situation voice reports from an occasional aircraft that is not equipped with data link.

Although the separation assurance decision-making process has a relatively large number of functions compared with the other control processes, it can still be broken down into monitoring, decision-action, and assessment subprocesses. (The functions making up these subprocesses may not be contiguous in the system descriptions.) The monitoring subprocess involves maintaining awareness of the air traffic situation and searching for potential conflicts and intervention action. The decision-action subprocess consists of confirming conflicts and determining specific clearances and advisories. The assessment subprocess consists of reviewing and revising a computer's recommended clearances and advisories as well as developing overall strategy for avoiding conflict. The first monitoring function in the process (function 11, where the routine air traffic situation is monitored) is downrated for the job satisfaction and motivation factors starting with System 3, the first system in which that function is automated. This is one of the primary jobs of the air

traffic controller, and its loss is felt in recognition, responsibility, skill utilization, challenge, and interest. The raters indicated, however, that less vigilance would be required once the monitoring of the routine air traffic situation were automated, and thus the level of stress on the controller would be reduced. Another monitoring function in this separation assurance process (function 15) is the conflict alert system implemented to detect imminent conflict situations. This function is considered to be fully automated throughout all the systems under consideration, but is given a low rating in terms of responsibility, skill utilization, and challenge only in Systems 5 and 6. This reduced rating corresponds to the controller's reduced participation in the entire separation assurance process. The raters also felt a reduction in stress beginning with System 3, where automation and integration of the functions concerned with planning and conflict avoidance become more complete.

The decision-action subprocess is composed of three functions. In function 17, the existence of a potential conflict is confirmed; in 18, a strategy to resolve the potential conflict is developed; and in 19, specific clearances and advisories are determined. The automation of these functions beginning in System 2 causes an immediate and significant drop in the ratings of recognition, responsibility, skill utilization, challenge, and interest. Simultaneously, a significant reduction in stress on the controller is recognized. Although functions 17, 18, and 19 are now handled automatically, function 20 reviewing the computer's assessment and recommended conflict resolution, seems to compensate for their loss (see Figure 6). The recognition factor is not rated above average for function 20; the reason for this may be that, although the raters see the review function as a challenging and interesting task that utilizes controller skills and requires a great amount of responsibility, the controller per se will not receive recognition for reviewing a computer's assessment of a conflict. The raters did see a significant increase in recognition for performing the revision function. Revision is an active, creative process; review is a passive one.

Beginning in System 2, the stress to a controller is reduced with the automation of the decision-action function. This is consistent with the rater's judgment of stress as other monitoring and decision-action functions become automated. However, for this process, the assessment functions are negatively compensatory in that the raters saw an increase in stress as the controller revised the computer-generated strategy, clearances, and advisories. [This fact is not indicated in Figure 6 because the degree of stress narrowly missed the criterion used to produce the figure (stress was judged at 2.1 for System 2; the cutoff value was 2.0).]

The separation assurance decision-making process is the only control process for which failure mode factors received critical scores. These scores were received in System 6 for the routine monitoring function (function 11) and the conflict alert system (function 15). It can be concluded that the raters were most concerned with tactical control of the sector and felt that problems would arise if the controller were entirely removed from the loop.

Rater responses and remarks concerning failure mode factors indicate that the descriptions of failure recovery operations were not precise enough to enable a rater to appreciate fully failure consequences. Therefore, critical failure mode factor scores could have been received for other systems had failure operations been described in more detail.

4. Flight Information Decision-Making Process

The flight information decision-making process consists of identifying the flight path clearance and information needs of each aircraft that have not been satisfied as part of the separation assurance process. In the current NAS/ARTS system this process is performed manually. In System 3 the computer identifies and electronically displays advisories or clearances which the controller reviews and accepts or revises. He also prepares supplemental advisories required by the aircraft. In Systems 4 through 6 the flight information decision-making process is performed automatically with no human involvement.

The process can be broken down into three subprocesses. The monitoring and decision-action functions are performed more or less simultaneously as the controller or computer determines specific clearances and advisories as the need arises. The assessment function consists of the controller reviewing or revising the computer-recommended flight information and adding advisories as necessary. Some of the job satisfaction and motivation factors (recognition, responsibility, skill utilization, challenge, interest) are rated significantly lower beginning in System 3, when the monitoring and decision-action functions become automated. The substitution of an assessment function for these functions does not seem to compensate the controller, however, since the assessment function is given only an average rating. The monitoring and decision-action functions are rated only slightly lower in Systems 4, 5, and 6 (where there is no assessment), which indicates that the performance of the assessment function holds little significance for a controller.

5. Control Message Transmission Process

The control message transmission process in the current NAS/ARTS system consists of a controller issuing voice clearance and advisories and updating paper and computer records. In System 4, the automatic machinery issues clearances by data link and electronically displays flight plan data updates. The controller confirms the clearance issuance by the computer and relays by voice the computer-generated clearances for non-data-link aircraft. Thus, beginning with System 4, the controller plays no part in the control message transmission process other than to interact with non-data-link aircraft. This has an adverse effect on the rater's judgment of recognition, responsibility, skill utilization, challenge, and interest. Neither the substitute action function--relaying clearances--nor the substitute function--reviewing

the computer-delivered clearances (System 4 only), are rated higher than average for any job satisfaction and motivation factor. These functions are therefore not seen as compensatory for manual delivery of clearances and information to all aircraft--a controller's sole interaction with pilots that is rated high in responsibility and recognition. The descriptions developed for the Control-by-Exception systems (Systems 4, 5, and 6) assume that only occasional aircraft would be without data-link equipment. Considering the relative infrequency of the necessity to relay clearances, and the fact that the controller is acting only as a conduit for computer-generated messages, it is easy to understand the raters' lack of enthusiasm for the substitution functions.

The amount of vigilance required to perform the monitoring function is reduced significantly in System 3 as is the stress involved in determining the specific clearances and advisories. The raters judged that little stress was produced by the assessment function, so there is no negative compensation in this case.

VI CONCLUSIONS

The results of this first-cut study of the impact of automation on air traffic control indicate that automation tends to reduce both the human rewards and the stress associated with ATC system operations. However, this reduction can be moderated to a degree by the introduction of new control functions into future ATC operations.

In System 1 (NAS/ARTS), the least automated of the ATC system configurations, the performance of planning and tactical control functions requires a high degree of intellectual involvement. Controllers have direct authority and responsibility for ATC system operations and are held accountable for their actions. They derive rewards in terms of job satisfaction and motivation, but they also experience stress. The position of authority and responsibility held by today's controller requires a commensurate degree of technical expertise and a commensurate capability to apply the expertise. A controller's technical expertise results from his extensive training in the complexities of ATC operations and his ability to mentally structure spatial relationships and logically assess the consequences of control actions. Today's controller must aggressively use highly specialized knowledge to make command decisions in a time-critical environment, coordinate his decisions with other controllers, and issue his decisions to pilots. The controller interacts with machines to obtain and process information and with other humans to negotiate and carry out decision making.

In System 2 (Enroute Decision Aid Automation with conflict probe), where the controller is required to review and revise computerized conflict resolution recommendations, little overall impact of automation on either job satisfaction and motivation or stress was perceived, apparently because highly developed skills are still required to critically review tactical control actions.

As planning and tactical control functions become more automated, the reduction in human planning and tactical control functions become more automated, the reduction in human rewards and stress becomes more pronounced. System 3 (Terminal Decision Aid Automation with metering and spacing) and Systems 4 and 5 (Control-by-Exception, Levels I and II, with control message automation and data link) require controllers to review computer-generated plans and tactical control operations. The automation of planning functions removes much of the direct human interactions among controllers and does not appear to introduce new control functions that significantly compensate for the loss of job satisfaction and motivation. However, automation of planning functions in System 3 was perceived to reduce stress. A reduction in stress and job satisfaction due to automating tactical control functions was evident in System 5 where controllers review conflict resolution strategies rather than the details of clearance and advisory messages. Although the review functions

retained by the controllers in Systems 3, 4, and 5 require a working knowledge of ATC operations, controllers experience fewer opportunities to apply their expert skills.

In System 6 (Control-by-Exception, Level III) job satisfaction and motivation rewards and stress are largely removed. The job of the controller is relegated to inputting and processing miscellaneous data. Controller skills required for this system need not be as highly developed as those of predecessor systems. As a result, controllers would be less competent to handle failure situations and would be much less likely to maintain awareness of the tactical sector situation.

In summary, System 2 seems to be the most promising of the future systems in terms of compatability between operational design and human factors. The conflict probe of System 2 would enable controllers to apply expert skills to critically review computerized actions and therefore would not severely limit their ability to exercise highly trained capabilities. System 6, where the controller is almost completely "out of the loop" but acts as overall systems manager, would be acceptable given a radical change in both the type of person performing the job and the training received. This of course assumes technological components of such quality and redundancy that a controller could be removed completely from the tactical ATC situation.

Because Systems 3, 4, and 5 reduce the opportunities of today's controllers to apply their expert skills, inconsistencies between human expectations and rewards, would result. For these systems, highly trained control skills equivalent to those of today's controllers would be necessary if the controller is expected to perform recovery operations in the event of automation failure. Underutilization of these expert skills, caused by removing the planning functions from the job responsibilities of controllers, appears to account in large part for reductions in job satisfaction and motivation rewards. Such underutilization of expert skills could also undermine the capabilities of controllers to respond to failures, regardless of their training.

Appendix A

SYSTEM 1: NAS/ARTS

Appendix A

SYSTEM 1: NAS/ARTS

Operational Overview

Technological Components

The current enroute NAS Stage A and terminal ARTS III ATC operations include air/ground (A/G) and interphone voice communications; automated flight data processing/forwarding; air traffic control radar beacon system (ATCRBS); automatic tracking displays with alphanumerics (including Mode C and reported altitudes and ground speed); automatic and manual display filters; surveillance data mosaicing (enroute only); simplified clearance/coordination procedures; conflict alert; minimum safe altitude warning (MSAW); and central flow control.

Sector Control Operation

The NAS/ARTS computer operation processes, forwards, and presents aircraft situation and flight plan data and control system data. The enroute and terminal sector controller(s) performs the decision-making requirements of each control process. He determines sector traffic flow plans (in coordination with other sector and flow controllers); defines flight path plans for aircraft under his jurisdiction; formulates strategies, clearance, and advisories for separation assurance and flight information requirements; and issues all control messages using A/G voice communications. These control activities may be preempted by conflict alerts or MSAWs, which the controller reviews and resolves by A/G voice.

To obtain and exchange data needed to carry out his responsibilities, the controller systematically scans a PVD traffic situation presentation, conducts A/G voice communications with pilots, coordinates with other controllers by means of interphone voice communications, reads computer-processed messages on a computer readout device (CRD), manually arranges and updates (by handwriting) paper flight strips, and manually inputs computer information by means of trackball and keyboard data processing devices.

Control Process Roles

The control process roles for the NAS/ARTS system are given in Table A-1.

Table A-1

SYSTEM 1: NAS/ARTS CONTROL PROCESS ROLES

Control Process	Role*
Sector traffic flow planning	M: The human(s) monitors data describing changes to the sector equipment and weather status, procedural constraints imposed by other sector or flow controllers, and the aggregate traffic situation and defines and coordinates a sector traffic flow plan. A: The computer(s) processes routine flight plan and sector operating situation data with paper and electronic displays.
Aircraft flight path planning	M: The human(s) monitors changing aircraft flight plan, track, and traffic situations and defines and finalizes a flight path plan for each sector aircraft. A: The computer(s) processes routine flight plan, track and sector traffic situation data with paper and electronic displays.
Separation assurance decision making	M: The human(s) monitors changing aircraft track and traffic situations, searches for control intervention situations, identifies potential conflicts, and defines and coordinates clearances and advisories to resolve the conflicts. The human also responds to computer alerts for emergency situations. A: The computer(s) processes routine flight plan, track, and sector operating situation data with paper and electronic displays, and searches for and alerts the controller of imminent conflicts.
Flight information decision making	M: The human(s) identifies the aircraft flight information needs that have not been satisfied as part of the separation assurance process and defines data service clearances and advisories. A: The computer(s) processes flight plan, track, and sector operating situation data with paper and electronic displays.
Control message transmission	M: The human(s) issues by voice the clearance and advisories and updates paper and computer records. A: The computer(s) forwards flight plan data updates with paper and electronic displays.

*M = man; A = automation.

Control Function Summary

Sector Traffic Flow Planning Process

1. Monitor changes to the sector operating status--M

The enroute or terminal controller updates his mental picture of the sector's status with respect to weather, ATC equipment, and procedural rule changes by receiving voice, paper-printed, or electronically displayed messages.

3. Determine a sector traffic flow plan--M

The controller devises the sector traffic flow plan he intends to implement. He defines the preferred routes and procedural altitude, speed, and spacing restrictions within the sector and at sector entry points that will complement the sector's operating status and observed traffic.

6. Issue the sector traffic flow plan--M

The controller coordinates his traffic flow plan with that of other controllers through interphone communication.

Aircraft Flight Path Planning Process

7. Monitor changes to the traffic flight plans--M

The controller receives flight plan updates for aircraft not yet in his sector, scans the PVD for aircraft approaching his sector, and accepts hand-offs on aircraft entering the sector.

8. Determine a flight path plan for an aircraft--M

The controller reviews the filed flight plan of an aircraft and checks its compatibility with the current traffic situation, accepts the plan as filed or modifies it as necessary, and updates paper and computer data records.

Separation Assurance Decision-Making Process

11. Monitor the routinely changing air traffic situation--M

The controller receives A/G voice reports and pilot requests and systematically scans the PVD in general for aircraft situation data.

14. Search for a potential control intervention action--M

The controller looks for indications of developing potential conflict situations by reviewing the flight path plans and situation data in order to recognize intersecting or coincidental flight paths.

15.* Search for an undetected imminent (emergency) conflict situation--A

This function is the automated conflict alert/MSAW operation and is performed in parallel with controller monitoring and searching.

16.* Monitor a computer report of an imminent (emergency) conflict situation--M

If an emergency is flagged (including graphical and message display) by the conflict alert or MSAW, the controller determines the specific clearances and advisories needed to resolve the conflict situation.

17. Confirm existence or nonexistence of a potential conflict--M

The controller reviews information pertinent to a potential conflict including aircraft type, visibility, and metering and spacing procedures. He selects appropriate separation rules, compares projected trajectory closure against those rules, and determines whether or not potential violations of separation exist.

18. Determine a strategy to resolve the potential conflict--M

The controller selects a strategy to resolve a confirmed potential conflict that is compatible with sector procedures and the traffic congestion environment. These include procedural separation (assignment of nonintersecting routes or altitudes) or tactical separation (vectors or speed controls).

19. Determine specific clearances and advisories to resolve the potential conflict--M

The controller calculates precise flight trajectory adjustments, determines specific clearances for potentially conflicting

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*Pertains to conflict alert and MSAW interruptions to routine control activities.

aircraft, and coordinates these clearances with other controllers if necessary.

Flight Information Decision Making Process

23. Search for a flight information service action (other than separation services)--M

The controller examines the projected flight path of an aircraft and reviews information that may be needed in order to ensure the aircraft's progress (if such information has not been determined as part of the separation assurance process).

24. Determine specific clearances and advisories to provide flight information service--M

The controller identifies precise flight information data requirements such as the need for route or altitude clearance, vectoring, weather information, or frequency change assignment.

Control Message Transmission Process

28. Issue clearances and advisories--M

The controller transmits voice messages to the aircraft, receives responses and acknowledgments, and updates paper and computer records.

Appendix B

SYSTEM 2: ENROUTE DECISION AID AUTOMATION

Appendix B

SYSTEM 2: ENROUTE DECISION AID AUTOMATION

Operational Overview

Technological Components

We envision the technological structure of this system to be composed of the following representative hardware/software capabilities:

- Current technology, including A/G and interphone voice communications, ATC radar beacon system (ATCRBS), flight data processing (FDP), conflict alert, and minimum safe altitude warning (MSAW).
- Information aids, including automated data handling (ADH) with tabular displays and touch-entry data processing, and area navigation (RNAV).
- Decision aids, including conflict probe, enroute metering, automated local flow control, automated central flow control.

Sector Control Operations

The enroute decision aid automation performs decision-making requirements for the separation assurance process but is managed by and subject to intervention by a controller (who issues all control messages using A/G voice communications). The computerized decision making is directed by conflict probe automation and is supplemented by flow control/metering automation; the latter specifies external procedural constraints to the controller's sector traffic flow planning.

The enroute sector controller(s) performs the sector traffic flow and aircraft flight path planning and manually enters planning and flight data not otherwise available to the computer. The conflict probe searches for and assesses potential conflict situations. The controller reviews and accepts or revises computer-recommended clearances and advisories to resolve potential conflicts; he also determines (without computer assistance) flight information clearances and advisories. These actions enable the controller to direct the conflict probe actions, integrate this automation service into his decision-making process, and formulate control messages for A/G voice transmission. These control activities may be preempted by computer-generated resolutions for conflict alerts or MSAWs which the controller issues by A/G voice.

To obtain and exchange data needed to carry out his responsibilities, the controller systematically scans a PVD traffic situation presentation, conducts A/G voice communications with pilots, reads computer-generated messages on an electronic tabular display, coordinates with other controllers using the tabular display with quick-action touch-entry data processing or by interphone voice communications, and manually processes computer data using the touch-entry device.

Control Process Roles

The control process roles for the enroute decision aid automation system are given in Table B-1.

Control Function Summary

Sector Traffic Flow Planning Process

1. Monitor changes to the sector operating status--M

   The enroute controller updates his mental picture of the sector's status with respect to weather, ATC equipment, and procedural rule changes by receiving voice or electronically displayed messages.

3. Determine a sector traffic flow plan--M

   The controller devises the sector traffic flow plan he intends to implement. He defines the preferred routes and procedural altitude, speed, and spacing restrictions within the sector and at sector entry points that will complement the sector's operating status and observed traffic.

6. Issue the sector traffic flow plan--M

   The controller coordinates his traffic flow plan with that of other controllers through interphone communication.

Aircraft Flight Path Planning Process

7. Monitor changes to the traffic flow plans--M

   The controller receives flight plan updates for aircraft not yet in his sector, scans the PVD for aircraft approaching his sector, and accepts hand-offs on aircraft entering the sector.

8. Determine a flight path plan for an aircraft--M

   The controller reviews the filed flight plan of an aircraft and checks its compatibility with the current traffic situation, accepts the plan as filed or modifies it as necessary, and updates computer data records.

Table B-1

SYSTEM 2: ENROUTE DECISION AID AUTOMATION
CONTROL PROCESS ROLES

Control Process	Role*
Sector traffic flow planning	**M:** The human(s) monitors data describing changes to the sector equipment and weather status, procedural constraints imposed by the flow control automation, and the aggregate traffic situation and defines and coordinates a sector traffic flow plan. **A:** The computer(s) processes and electronically displays routine flight plan, track, and sector operating situation data (enhanced by flow control automation).
Aircraft flight path planning	M: The human(s) monitors changing aircraft flight plan, track, and traffic situations and defines and finalizes a flight path plan for each sector aircraft. A: The computer(s) processes and electronically displays routine flight plan, track, and sector operating situation data.
Separation assurance decision making	M: The human(s) monitors changing aircraft track and traffic situations, searches for control intervention situations, calls for and instructs automated conflict probe situation assessments, and reviews, accepts or revises, and coordinates computer-recommended conflict resolution clearances and advisories. The human also responds to computer alerts for emergency situations. A: The computer performs conflict probe actions as instructed by the controller (i.e., automatically identifies potential conflicts and recommends resolution actions), automatically performs conflic alert operations, and processes and electronically displays routine flight plan, track, and sector operating situation data.
Flight information decision making	M: The human(s) identifies the flight information needs of aircraft that have not been satisfied as part of the separation assurance process and defines the data service clearances and advisories. A: The computer(s) processes and electronically displays routine flight plan, track, and sector operating situation data.
Control message transmission	M: The human(s) issues by voice the clearance and advisories and updates computer records. A: The computer(s) forwards and electronically displays flight plan data updates.

*M = man; A = automation.

Separation Assurance Decision-Making Process

11. Monitor the routinely changing air traffic situation--M

The controller receives A/G voice reports and pilot requests and systematically scans the PVD in general for aircraft situation data.

13. Establish automated processing of control intervention actions--M

The enroute controller inputs information not otherwise available to the computer, such as pilot voice reports and requests and the status and identity of aircraft on the A/G frequency. Such actions initiate and update the automated conflict probe and enable the controller to call for specific conflict searches (especially when aircraft first call in on frequency).

15.* Search for an undetected imminent (emergency) conflict situation--A

This function is the automated conflict alert/MSAW operation and is performed in parallel with controller monitoring.

16.* Monitor a computer report of an imminent (emergency) conflict situation--M

If an emergency is flagged (including graphical message display) by the conflict alert or MSAW, the controller determines the specific clearances and advisories needed to resolve the conflict situation.

17. Confirm existence or nonexistence of a potential conflict--A

18. Determine a strategy to resolve the potential conflict--A

19. Determine specific clearances and advisories to resolve the potential conflict--A

The computerized conflict probe searches for and confirms a potential conflict situation, defines an appropriate strategy to resolve the conflict, and defines specific clearances and advisories to implement the resolution strategy.

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*Pertains to conflict alert and MSAW interruptions to routine control activities.

20. Review the computer assessment and recommended resolution of a potential conflict--M

The controller receives a graphical display of a potential conflict situation as well as electronically displayed messages including the quantitative data regarding the situation and recommended clearances and advisories. The controller identifies the recommended resolution strategy, compares the projected trajectories against the appropriate separation rules and the sector procedural plan, and accepts or rejects the computer recommendations.

21. Revise the computer-recommended strategy, clearances, and advisories to resolve the potential conflict--M

If the controller rejects the computer-recommended actions, he mentally revises the strategy, calculates precise flight trajectory adjustments, defines clearances and advisories, and coordinates the clearances with other controllers as necessary.

Flight Information Decision-Making Process

23. Search for a flight information service action (other than separation services)--M

The controller examines the projected flight path of an aircraft and reviews information that may be needed in order to ensure the aircraft's progress (if such information has not been determined as part of the separation assurance process).

24. Determine specific clearances and advisories to provide flight information service--M

The controller identifies precise flight information data requirements such as the need for route or altitude clearances, vectoring, weather information, or frequency change assignment.

Control Message Transmission Process

28. Issue clearances and advisories--M

The controller transmits voice messages to the aircraft, receives responses and acknowledgments, and updates computer records.

Appendix C

SYSTEM 3: TERMINAL DECISION AID AUTOMATION

Appendix C

SYSTEM 3: TERMINAL DECISION AID AUTOMATION

Operational Overview

Technological Components

We envision the technological structure of this system to be composed of the following representative hardware/software capabilities:

- Current technology, including A/G and interphone voice communications, ATC radar beacon system (ATCRBS), flight data processing (FDP), conflict alert, and minimum safe altitude warning (MSAW).
- Information aids, including automated data handling (ADH) with tabular displays and touch-entry data processing, wind shear advisory, microwave landing system (MLS), area navigation (RNAV), and airport surface traffic control (ASTC).
- Decision aids, including refined metering and spacing, automated wake vortex avoidance system (WVAS), and central flow control.

Sector Control Operation

The terminal decision aid automation performs the decision-making requirements for the sector traffic flow and aircraft flight path planning processes, the separation assurance control message definition process, and the basic aspects of flight information message identification. These functions are managed by and subject to intervention by the controller, who issues all control messages using A/G voice communications. The computerized operation is directed by metering and spacing automated in coordination with flow control and metering automation.

The terminal sector controller(s) reviews and accepts or revises the computer-recommended sector traffic flow plans, aircraft flight path plans, and specific clearances and advisories to resolve potential conflicts and satisfy essential flight information needs. The controller determines supplementary flight information messages (in addition to the basic requirements recommended by the controller) and manually enters sector status data and flight information (including voice message data) not otherwise available to the computer. These actions enable the controller to maintain cognizance of and exercise directive authority over the control automation so that he may mentally assimilate computer-generated plans and control messages and issue A/G voice clearances and

advisories. These control activities may be preempted by computer-generated resolutions for conflict alerts or MSAWs, which the controller issues by A/G voice.

To obtain and exchange data needed to carry out his responsibilities, the controller reads computer-generated messages on an electronic tabular display, selectively scans a PVD traffic situation presentation, conducts A/G voice communications with pilots, coordinates with other controllers using the tabular display with quick-action tough-entry data processing or by interphone voice communications, and manually processes computer data using the touch-entry device.

Control Process Roles

The control process roles for the terminal decision and automation system are given in Table C-1.

Control Function Summary

Sector Traffic Flow Planning Process

1. Monitor changes to the sector operating status--M

   The terminal controller updates his mental picture of the sector's status with respect to weather, ATC equipment, and procedural rule changes by receiving voice or electronically displayed messages.

2. Establish the automated processing of a sector traffic flow plan--M

   The controller inputs data not otherwise available to the computer describing revisions to the sector's equipment status, weather status, and procedural constraints. This data entry instructs the computer to devise a sector traffic flow plan.

3. Determine a sector traffic flow plan--A

   The computerized flow control and metering and spacing operation automatically defines a sector traffic flow plan including preferential routes, altitudes, speeds, and spacing restrictions.

4. Review the computer-recommended sector traffic flow plan--M

   The controller receives the electronically displayed computer-recommended sector traffic flow plan. He compares this plan with the sector operating status and the aggregate traffic congestion situation as presented on a PVD and accepts or rejects the computer's recommendation.

Table C-1

SYSTEM 3: TERMINAL DECISION AID AUTOMATION
CONTROL PROCESS ROLES

Control Process	Role*
Sector traffic flow planning	M: The human(s) monitors data (some of which is not available to the computer) describing changes to the sector equipment and weather status and procedural constraints imposed by flow control automation, updates computer records, and reviews, accepts or revises, and coordinates the computer-recommended sector traffic flow plan. A: The computer(s) reviews the sector operating status (as updated by the controller), procedural constraints imposed by the flow control automation, and the aggregate traffic situation and defines and electronically displays a sector traffic flow plan.
Aircraft flight path planning	M: The human(s) receives and accepts or revises the computer-recommended flight path plan for each aircraft. A: The computer(s) monitors aircraft flight plan, track, and traffic situations and defines and electronically displays a flight path plan for each sector aircraft.
Separation assurance decision making	M: The human(s) monitors flight data not available to the computer (i.e., pilot voice reports and requests), updates computer records, reviews computer assessments of potential conflict situations, and accepts or revises and coordinates the computer-recommended conflict resolution clearances and advisories. The human also responds to computer alerts for emergency situations. A: The computer(s) monitors the changing aircraft track and traffic situations (including the controller updates), searches for control intervention situations, identifies potential conflicts, and defines and electronically displays clearances and advisories to resolve the conflicts.
Flight information decision making	M: The human(s) reviews and accepts or revises basic flight information clearances recommended by the computer and determines supplemental advisories required by the aircraft. A: The computer(s) identifies and electronically displays the flight path clearance information (exclusive of general flight circumstances data) needs of each aircraft that have not been satisfied as part of the separation assurance process.
Control message transmission	M: The human(s) issues by voice the clearance and advisories and updates computer records. A: The computer(s) forwards and electronically displays flight plan data updates.

*M = man; A = automation.

5. Revise the computer-recommended sector traffic flow plan--M

If the controller rejects the computer's plan, he defines an alternative sector traffic flow plan and inputs its parameters to the computer.

6. Issue the sector traffic flow plan--A

The computer automatically communicates the features of the sector traffic flow plan to other controllers.

Aircraft Flight Path Planning Process

7. Monitor changes to traffic flight plans--A

8. Determine a flight path plan for an aircraft--A

The computerized metering and spacing operation tracks aircraft trajectories, reviews filed flight plans, checks flight plan compatibility with the sector traffic flow plan and current traffic situation, and accepts a flight plan as filed or modifies it as necessary.

9. Review the computer-recommended flight path plan--M

The controller reviews the electronically displayed computer-recommended flight path plan in order to remain aware of the ATC situation, to check on the plan's validity relative to the sector traffic flow plan, and to accept or reject the computer's recommendation.

10. Revise the computer-recommended flight path plan--M

If the recommended flight path plan is rejected, the controller selects procedural restrictions that correct the deficiencies in the computer-recommended plan and inputs new parameters to the computer.

Separation Assurance Decision-Making Process

11. Monitor the routinely changing aircraft situation--A

The computerized metering and spacing operation automatically tracks the movement of air traffic through the sector's airspace.

12. Monitor only routinely changing air traffic situations reported by pilots--M

The controller receives A/G pilot voice reports and requests and selectively scans the PVD for specific aircraft situation data.

13. Establish automated processing of control intervention actions--M

The terminal controller inputs information not otherwise available to the computer, such as pilot voice reports and requests and the status and identity of aircraft on the A/G frequency. Such actions update the automated metering and spacing operation.

15.* Search for an undetected imminent (emergency) conflict situation--A

This function is the automated conflict alert/MSAW operation and is performed in parallel with automated metering and spacing and controller monitoring.

16.* Monitor a computer report of an imminent (emergency) conflict situation--M

If an emergency is flagged (including graphical and message display) by the conflict alert or MSAW, the controller determines the specific clearances and advisories needed to resolve the conflict situation.

17. Confirm existence or nonexistence of a potential conflict--A

18. Determine a strategy to resolve the potential conflict--A

19. Determine specific clearances and advisories to resolve the potential conflict--A

The computerized metering and spacing operation searches for and confirms a potential conflict situation, defines an appropriate strategy to resolve the conflict, and defines specific clearances and advisories to implement the resolution strategy.

20. Review the computer assessment and recommended resolution of a potential conflict--M

The controller receives a graphical display of a potential conflict situation as well as electronically displayed messages including quantitative data regarding the situation and recommended clearances and advisories. The controller identifies the recommended resolution strategy, compares the projected trajectories with the appropriate separation rules and the sector procedural plan, and accepts or rejects the computer's recommendations.

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*Pertain to conflict alert and MSAW interruptions to routine control activities.

21. Revise the computer-recommended strategy, clearances, and advisories to resolve the potential conflict--M

If the controller rejects the computer-recommended actions, he mentally revises the recommended strategy, calculates precise flight trajectory adjustments, defines clearances and advisories, and coordinates the clearances with other controllers as necessary.

Flight Information Decision-Making Process

23. Search for a flight information service action--A

24. Determine specific clearances and advisories to provide flight information services--A

The computerized metering and spacing operation identifies essential clearances and advisories required by the aircraft to proceed along their flight paths (if such information has not been determined as part of the separation assurance process).

25. Review computer-recommended action for flight information service--M

The controller reviews the electronically displayed clearances by the computer in order to remain aware of the ATC situation, to check on the clearances' validity relative to the flight plan and the sector procedural plan, and to accept or reject the computer's recommendation.

26. Determine advisories to supplement the computer-recommended clearances--M

If the controller accepts the computer-recommended clearances, he reviews the advisory issuance history of an aircraft, compares it with its flight plan and flight data needs, and identifies additional advisory information if necessary.

27. Revise computer-recommended flight information service action--M

If the controller rejects the computer-recommended flight information clearances, he formulates corrected clearances and supplemental advisories.

Control Message Transmission Process

28. Issue clearances and advisories--M

The controller transmits voice messages to the aircraft, receives responses and acknowledgments, and updates computer records.

13. Establish automated processing of control intervention actions--M

The terminal controller inputs information not otherwise available to the computer, such as pilot voice reports and requests and the status and identity of aircraft on the A/G frequency. Such actions update the automated metering and spacing operation.

15.* Search for an undetected imminent (emergency) conflict situation--A

This function is the automated conflict alert/MSAW operation and is performed in parallel with automated metering and spacing and controller monitoring.

16.* Monitor a computer report of an imminent (emergency) conflict situation--M

If an emergency is flagged (including graphical and message display) by the conflict alert or MSAW, the controller determines the specific clearances and advisories needed to resolve the conflict situation.

17. Confirm existence or nonexistence of a potential conflict--A

18. Determine a strategy to resolve the potential conflict--A

19. Determine specific clearances and advisories to resolve the potential conflict--A

The computerized metering and spacing operation searches for and confirms a potential conflict situation, defines an appropriate strategy to resolve the conflict, and defines specific clearances and advisories to implement the resolution strategy.

20. Review the computer assessment and recommended resolution of a potential conflict--M

The controller receives a graphical display of a potential conflict situation as well as electronically displayed messages including quantitative data regarding the situation and recommended clearances and advisories. The controller identifies the recommended resolution strategy, compares the projected trajectories with the appropriate separation rules and the sector procedural plan, and accepts or rejects the computer's recommendations.

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*Pertain to conflict alert and MSAW interruptions to routine control activities.

Appendix D

SYSTEM 4: CONTROL-BY-EXCEPTION (LEVEL I)

Appendix D

SYSTEM 4: CONTROL-BY-EXCEPTION (LEVEL I)

Operational Overview

Technological Components

We envision the technological structure of this system to be composed of the following representative hardware/software capability:

- Current technology, including A/G and interphone voice communications, conflict alert, and minimum safe altitude warning (MSAW).
- Information aids, including automated data handling (ADH) with tabular display and touch-entry data processing, microwave landing system (MLS), area navigation (RNAV), and airport surface traffic control (ASTC).
- Decision aids, including enroute metering, automated local flow control, automated central flow control, and automated wake vortex avoidance system (WVAS).
- Decision automation, including control message automation (CMA), data link, automatic traffic advisory and resolution service (ATARS), and discrete address beacon system (DABS).

Sector Control Operation

The enroute and terminal control-by-exception Level I operation automatically performs the decision-making requirements of each control process and conducts data link communications with aircraft but is subject to human intervention in regard to its sector traffic flow and aircraft flight path planning and separation assurance detailed message formulation functions. The flight information decision process is <u>not</u> subject to human intervention. The computerized operation is directed by control message automation in coordination with flow control/metering automation.

The enroute and terminal sector controller(s) reviews and accepts or revises the computer-recommended sector traffic flow plans, aircraft flight path plans, and specific clearances and advisories to resolve potential conflicts. He also manually enters some sector status and flight data not otherwise available to the computer. These actions enable the controller to maintain cognizance of and exercise direction over the details of the separation assurance activities. He does not critically assess or routinely concern himself with computer-generated flight information clearances and advisories; the computerized operation

is assumed to be capable of generating valid flight information messages. Clearances and advisories are issued by data link, except for those few messages requiring voice relay by the controller (e.g., communications with infrequent non-data-link aircraft). These control activities may be preempted by ATARS/conflict alerts or MSAWs, which are monitored by the controller.

To obtain and exchange data needed to carry out his responsibilities, the controller reads computer-generated messages on an electronic tabular display, visually studies selected traffic situations on a PVD-like graphical presentation, and manually inputs data to the computer using a quick-action, touch-entry device. If necessary, he coordinates with other controllers using the tabular display with touch-entry data processing or by interphone voice communications and conducts some A/G voice communications with pilots.

Control Process Roles

The control process roles for the control-by-exception (Level I) system are given in Table D-1.

Control Function Summary

Sector Traffic Flow Planning Process

1. Monitor changes to the sector operating status--M

   The enroute or terminal controller updates his mental picture of the sector's status with respect to weather, ATC equipment, and procedural rule changes by receiving voice or electronically displayed messages.

2. Establish the automated processing of a sector traffic flow plan--M

   The controller inputs data not otherwise available to the computer describing revisions to the sector's equipment status, weather status, and procedural constraints. This data entry instructs the computer to devise a sector traffic flow plan.

3. Determine a sector traffic flow plan--A

   The computerized flow control and control message automation defines a sector traffic flow plan including preferential routes, altitudes, speeds, and spacing restrictions.

Table D-1

SYSTEM 4: CONTROL-BY-EXCEPTION (LEVEL I)
CONTROL PROCESS ROLES

Control Process	Role*
Sector traffic flow planning	M: The human(s) monitors data (some of which is not available to the computer) describing changes to the sector equipment and weather status and procedural constraints imposed by flow control automation, updates computer records, and reviews, accepts or revises, and coordinates the computer-recommended sector traffic flow plan. A: The computer(s) reviews the sector operating status (as updated by the controller), procedural constraints imposed by the flow control automation, and the aggregate traffic situation and defines and electronically displays a sector traffic flow plan.
Aircraft flight path planning	M: The human(s) reviews and accepts or revises the computer-recommended flight path plan for each sector aircraft. A: The computer(s) monitors aircraft flight path plan, track, and traffic situations and defines and electronically displays a flight path plan for each sector aircraft.
Separation assurance decision making	M: The human(s) monitors flight data not available to the computer (i.e., pilot voice reports and requests from non-data-link aircraft), updates computer records, reviews computer assessments of potential conflict situation, and accepts or revises and coordinates computer-recommended conflict resolution clearances and advisories. The human also monitors computer alerts for emergency situations. A: The computer(s) monitors the changing aircraft track and traffic situations (including the controller updates), searches for control intervention situations, identifies potential conflicts, and defines and electronically displays clearances and advisories to resolve the conflicts.
Flight information decision making	M: No human involvement. A: The computer(s) identifies the flight path clearance and advisory information needs of each aircraft that have not been satisfied as part of the separation assurance process.
Control message transmission	M: The human(s) confirms the issuance by the computer of potential conflict resolution clearances and advisories and relays by voice (without further critical assessment) computer-delayed clearances and advisories for non-data-link aircraft. A: The computer(s) issues clearances and advisories by data link and forwards and electronically displays flight plan data updates.

*M = man; A = automation.

4. Review the computer-recommended sector traffic flow plan--M

The controller receives the electronically displayed computer-recommended sector traffic flow plan. He compares this plan with the sector operating status and the aggregate traffic situation as presented on a PVD and accepts or rejects the computer's recommendation.

5. Revise the computer-recommended sector traffic flow plan--M

If the controller rejects the computer's plan, he defines an alternative sector traffic flow plan and inputs its parameters to the computer.

6. Issue the sector traffic flow plan--A

The computer automatically communicates the features of the sector traffic flow plan to other controllers.

Aircraft Flight Path Planning Process

7. Monitor changes to traffic flight plans--A

8. Determine a flight path plan for an aircraft--A

The computerized control message automation tracks aircraft trajectories, reviews filed flight plans, checks flight plan compatibility with the sector traffic flow plan and current traffic situation, and accepts the flight plan as filed or modifies it as necessary.

9. Review the computer-recommended flight path plan--M

The controller reviews the electronically displayed computer-recommended flight path plan in order to remain aware of the ATC situation, to check on the plan's validity relative to the sector traffic flow plan, and to accept or reject the computer's recommendation.

10. Revise the computer-recommended flight path plan--M

If the recommended flight path plan is rejected, the controller selects procedural restrictions that correct the deficiencies in the computer's recommendation and inputs new parameters to the computer.

Separation Assurance Decision-Making Process

11. Monitor the routinely changing aircraft situation--A

The computerized control message automation tracks the movement of air traffic through the sector's airspace.

12. Monitor only routinely changing air traffic situations reported by pilots--M

The controller receives initial call-ins from all aircraft coming onto the A/G voice frequency and maintains communications with the occasional non-data-link aircraft.

13. Establish automated processing of control intervention actions--M

The enroute or terminal controller inputs information not otherwise available to the computer, such as the status and identity of aircraft on the A/G frequency. He also inputs information to the computer concerning the requests of those few non-data-link aircraft.

15.* Search for an undetected imminent (emergency) conflict situation--A

This function is the automated conflict alert/ATARS/MSAW operation and is performed in parallel with control message automation and controller monitoring.

16.* Monitor a computer report of an imminent (emergency) conflict situation--M

If an emergency is flagged (including graphical and message display) by the conflict alert/ATARS/MSAW, the controller maintains awareness of the situation being processed by the automated operation.

17. Confirm existence or nonexistence of a potential conflict--A

18. Determine a strategy to resolve the potential conflict--A

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*Pertains to conflict alert, ATARS, and MSAW interruptions to routine control activities.

19. Determine specific clearances and advisories to resolve the potential conflict--A

The computerized control message automation searches for and confirms a potential conflict situation, defines an appropriate strategy to resolve the conflict, and defines specific clearances and advisories to implement the resolution strategy.

20. Review the computer assessment and recommended resolution of a potential conflict--M

The controller receives a graphical display of a potential conflict situation as well as electronically displayed messages including quantitative data regarding the situation and recommended clearances and advisories. The controller identifies the recommended resolution strategy, compares the projected trajectories with the appropriate separation rules and the sector procedural plan, and accepts or rejects the computer's recommendations.

21. Revise the computer-recommended strategy, clearances, and advisories to resolve the potential conflict--M

If the controller rejects the computer-recommended actions, he mentally revises the recommended strategy, calculates precise flight trajectory adjustments, defines clearances and advisories, and updates computer records.

Flight Information Decision-Making Process

23. Search for a flight information service action--A

24. Determine specific clearances and advisories to provide flight information service--A

The computerized control message automation identifies all specific clearances and advisories required by the aircraft to proceed along their flight paths (if such information has not been determined as part of the separation assurance process).

Control Message Transmission Process

28. Issue clearances and advisories--A

The computer automatically transmits digitized control instructions to data-link-equipped aircraft.

29. Review computer-transacted clearances and advisories--M

The controller monitors electronically displayed reports of the status of data-link-transmitted messages that he has reviewed as part of the separation assurance process.

30. Relay clearances and advisories--M

The controller receives electronically displayed message instructions, communicates by voice with pilots of an occasional non-data-link aircraft or retransmits messages that could not be completed successfully by data link, and updates computer records.

Appendix E

SYSTEM 5: CONTROL-BY-EXCEPTION (LEVEL II)

Appendix E

SYSTEM 5: CONTROL-BY-EXCEPTION (LEVEL II)

Operational Overview

Technological Components

We envision the technological structure of this system to be composed of the following representative hardware/software capability:

- Current technology, including A/G and interphone voice communications, conflict alert, and minimum safe altitude warning (MSAW).
- Information aids, including automated data handling (ADH) with tabular display and touch-entry data processing, microwave landing system (MLS), area navigation (RNAV), and airport surface traffic control (ASTC).
- Decision aids, including enroute metering, automated local flow control, automated central flow control, and automated wake vortex avoidance system (WVAS).
- Decision automation, including control message automation (CMA), data link, automatic traffic advisory and resolution service (ATARS), and discrete address beacon system (DABS).

Sector Control Operation

The enroute and terminal control-by-exception Level II operation automatically performs the decision-making requirements of each control process and conducts data link communications with aircraft. It is subject to human intervention only in regard to its separation assurance strategies. The computerized operation is directed by control message automation in coordination with flow control/metering automation.

The enroute and terminal sector controller(s) reviews without critical assessment and accepts the computer-recommended sector traffic flow and aircraft flight path plans and thereby maintains cognizance of the planning operations without directing them (although he does manually enter some sector status and flight data not otherwise available to the computer). The controller reviews and accepts or revises computer-recommended strategies to resolve potential conflicts and thereby maintains cognizance of and exercises direction over the computerized separation assurance process. He does not critically assess or routinely concern himself with the specific separation assurance or flight information clearances and advisories generated by the computer; the computerized

operation is assumed to be suitably refined to generate valid clearances and advisories. The clearances and advisories are issued by data link, except for those few messages requiring voice relay by the controller (e.g., communications with infrequent non-data-link aircraft). These control activities may be preempted by ATARS/conflict alerts or MSAWs, which are monitored by the controller.

To obtain and exchange data needed to carry out his responsibilities, the controller reads computer-generated messages on an electronic tabular display, visually studies selected traffic situations on a PVD-like graphical presentation, and manually inputs data to the computer using a quick-action, touch-entry device. If necessary, he coordinates with other controllers using the tabular display with touch-entry data processing or by interphone voice communication and conducts some A/G voice communications with pilots.

Control Process Roles

The control process roles for the control-by-exception (Level II) system are given in Table E-1.

Control Function Summary

Sector Traffic Flow Planning Process

1. Monitor changes to the sector operating status--M

   The enroute or terminal controller updates his mental picture of the sector's status with respect to weather, ATC equipment, and procedural rule changes by receiving voice or electronically displayed messages.

2. Establish the automated processing of a sector traffic flow plan--M

   The controller inputs data not otherwise available to the computer describing revisions to the sector's equipment status, weather status, and procedural constraints. This data entry instructs the computer to devise a sector traffic flow plan.

3. Determine a sector traffic flow plan--A

   The computerized flow control and control message automation defines a sector traffic flow plan including preferential routes, altitude, speeds, and spacing restrictions.

Table E-1

SYSTEM 5: CONTROL-BY-EXCEPTION (LEVEL II)
CONTROL PROCESS ROLES

Control Process	Role*
Sector traffic flow planning	M: The human(s) monitors data (some of which is not available to the computer) describing the changes to the sector equipment and weather status and procedural constraints imposed by flow control automation, updates computer records, and reviews (without critical assessment) and accepts the computer-recommended sector traffic flow plan. A: The computer(s) reviews the sector operating status (as updated by the controller), procedural constraints imposed by flow control automation, and the aggregate traffic situation and defines and electronically displays a sector traffic flow plan.
Aircraft flight path planning	M: The human(s) reviews (without critical assessment) and accepts the computer-recommended flight path plan for each sector aircraft. A: The computer(s) monitors aircraft flight plan, track, and traffic situations and defines and electronically displays a flight path plan for each sector aircraft.
Separation assurance decision making	M: The human(s) monitors flight data not available to the computer (i.e., pilot voice reports and requests from non-data-link aircraft), updates computer records, reviews computer assessments of potential conflict situations, and accepts or revises and coordinates computer-recommended conflict resolution strategies (without critically reviewing specific clearances and advisories). The human also monitors computer alerts for emergency situations. A: The computer(s) monitors the changing aircraft track and traffic situations (including the controller updates), searches for control intervention situations, identifies potential conflicts, defines conflict resolution clearances and advisories, and electronically displays the corresponding conflict resolution strategy.
Flight information decision making	M: No human involvement. A: The computer(s) identifies the flight path clearance and advisory information needs of each aircraft that have not been satisfied as part of the separation assurance process.
Control message transmission	M: The human(s) relays by voice (without further critical assessment) computer-displayed clearances and advisories for non-data-link aircraft. A: The computer(s) issues clearances and advisories by data link and forwards and electronically displays flight plan data updates.

*M = man; A = automation.

4. Review the computer-recommended sector traffic flow plan--M

The controller receives and reviews the electronically displayed computer-recommended sector traffic flow plan in order to remain aware of the ATC environment.

6. Issue the sector traffic flow plan--A

The computer automatically communicates the features of the sector traffic flow plan to other controllers.

Aircraft Flight Path Planning Process

7. Monitor changes to traffic flight plans--A

8. Determine a flight path plan for an aircraft--A

The computerized control message automation tracks aircraft trajectories, reviews filed flight plans, checks flight plan compatibility with the sector traffic flow plan and current traffic situation, and accepts the flight plan as filed or modifies it as necessary.

9. Review the computer-recommended flight path plan--M

The controller reviews the electronically displayed computer-recommended flight path plan in order to remain aware of the ATC situation.

Separation Assurance Decision-Making Process

11. Monitor the routinely changing aircraft situation--A

The computer automatically tracks the movement of air traffic through the sector's airspace.

12. Monitor only routinely changing air traffic situations reported by pilots--M

The controller receives initial call-ins from all aircraft coming onto the A/G voice frequency and maintains communications with the occasional non-data-link aircraft.

13. Establish automated processing of control intervention actions--M

The enroute or terminal controller inputs information not otherwise available to the computer, such as the status and identity of aircraft on the A/G frequency. He also inputs information to the computer concerning the requests of those few non-data-link aircraft.

15.* Search for an undetected imminent (emergency) conflict situation--A

This function is the automated conflict alert/ATARS/MSAW operation and is performed in parallel with control message automation and controller monitoring.

16.* Monitor a computer report of an imminent (emergency) conflict situation--M

If an emergency is flagged (including graphical and message display) by the conflict alert/ATARS/MSAW, the controller maintains awareness of the situation being processed by the automated operation.

17. Confirm existence or nonexistence of a potential conflict--A

18. Determine a strategy to resolve the potential conflict--A

19. Determine specific clearance and advisories to resolve the potential conflict--A

The computerized control message automation searches for and confirms a potential conflict situation, defines an appropriate strategy to resolve the conflict, and defines specific clearances and advisories to implement the resolution strategy.

20. Review the computer assessment and recommended resolution of a potential conflict--M

The controller receives a graphical display of a potential conflict situation as well as electronically displayed messages including quantitative data regarding the situation and recommended resolution strategy. The controller compares the recommended resolution strategy with the sector procedural plan and traffic congestion situation and accepts or rejects the computer's recommendation.

22. Revise only the computer-recommended strategy to resolve the potential conflict-M

If the controller rejects the computer-recommended plan, he defines an alternative strategy that is compatible with the sector traffic flow plan and traffic congestion situation. He enters the revised conflict resolution strategy into the computer by specifying the quantitative parameters of the tactical or procedural control technique that he favors. The automated operation determines the specific clearances and advisories required.

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*Pertains to conflict alert, ATARS, and MSAW interruptions to routine control activities.

Flight Information Decision-Making Process

23. Search for a flight information service action--A

24. Determine specific clearances and advisories to provide flight information service--A

The computerized control message automation identifies all specific clearances and advisories required by the aircraft to proceed along their flight paths (if such information has not been determined as part of the separation assurance process).

Control Message Transmission Process

28. Issue clearances and advisories--A

The computer automatically transmits digitized control instructions to data-link-equipped aircraft.

30. Relay clearances and advisories--M

The controller receives electronically displayed message instructions, communicates by voice with pilots on occasional non-data-link aircraft or retransmits messages that could not be completed successfully by data link, and updates computer records.

Appendix F

SYSTEM 6: CONTROL-BY-EXCEPTION (LEVEL III)

Appendix F

SYSTEM 6: CONTROL-BY-EXCEPTION (LEVEL III)

Operational Overview

Technological Components

We envision the technological structure of this system to be composed of the following representative hardware/software capability:

- Current technology, including A/G and interphone voice communications, conflict alert, and minimum safe altitude warning (MSAW).
- Information aids, including automated data handling (ADH) with tabular display and touch-entry data processing, microwave landing system (MLS), area navigation (RNAV), and airport surface traffic control (ASTC).
- Decision aids, including *enroute* metering, automated local flow control, automated central flow control, and automated wake vortex avoidance system (WVAS).
- Decision automation, including control message automation (CMA), data link, automatic traffic advisory and resolution service (ATARS), and discrete address beacon system (DABS).

Sector Control Operations

The enroute and terminal control-by-exception Level III operation automatically performs the decision-making requirements of each control process and conducts data link communications with aircraft. It is not subject to human intervention. The computerized operation is directed by control message automation in coordination with flow control/metering automation.

The enroute and terminal sector controller(s) is removed from all critical assessment requirements but manually enters some sector status and flight data not otherwise available to the computer. The computerized operation is assumed to be suitably reliable to generate valid sector traffic flow, aircraft flight path plans, and separation assurance and flight information clearances and advisories. The clearances and advisories are issued by data link, except for those few messages requiring voice relay by the controller (e.g., communications with infrequent non-data-link aircraft). These control activities may be preempted by ATARS/conflict alerts or MSAWs which are monitored by the controller.

To obtain and exchange data needed to carry out his responsibilities, the controller conducts some A/G communications with pilots and manually inputs data to the computer using a quick-action, touch-entry device. If necessary, he may monitor selected (e.g., emergency) traffic situations on a PVD-like graphical presentation, read computer-generated messages on an electronic tabular display, and coordinate with other controllers using the tabular display with touch-entry data processing or by voice interphone communications.

Control Process Roles

The control process roles for the control-by-exception (Level III) system are given in Table F-1.

Control Function Summary

Sector Traffic Flow Planning Process

1. Monitor changes to the sector operating status--M

   The enroute or terminal controller receives some raw data (i.e., noncomputerized) describing changes to the sector's status with respect to weather and ATF equipment by receiving voice messages.

2. Establish the automated processing of a sector traffic flow plan--M

   The controller inputs data not otherwise available to the computer describing revisions to the sector's equipment status and weather status. This data entry instructs the computer to devise a sector traffic flow plan.

3. Determine a sector traffic flow plan--A

   The computerized flow control and control message automation defines a sector traffic flow plan including preferential routes, altitudes, speeds, and spacing restrictions.

6. Issue the sector traffic flow plan--A

   The computer automatically communicates the features of the sector traffic flow plan to other controllers.

Table F-1

SYSTEM 6: CONTROL-BY-EXCEPTION (LEVEL III)

CONTROL PROCESS ROLES

Control Process	Role*
Sector traffic flow planning	M: The human(s) monitors some data not available to the computer describing the changes to the sector equipment and weather status and updates computer records. The human does not review the computer-recommended sector traffic plan. A: The computer(s) reviews the sector operating status (as updated by the controller), procedural constraints imposed by flow control automation, and the aggregate traffic situation and defines the sector traffic flow plan.
Aircraft flight path planning	M: No human involvement. A: The computer(s) monitors aircraft flight plan, track, and traffic situations and defines a flight path plan for each sector aircraft.
Separation assurance decision making	M: The human(s) monitors flight data not available to the computer (i.e., pilot voice reports and request from non-data-link aircraft) and updates computer records (without critically reviewing computer-recommended potential conflict actions). The controller also monitors computer alerts for emergency situations. A: The computer(s) monitors the changing aircraft track and traffic situations (including controller updates), searches for control intervention situations, identifies potential conflicts, and defines conflict resolution clearances and advisories.
Flight information decision making	M: No human involvement. A: The computer(s) identifies the flight path clearance and information needs of each aircraft that have not been satisfied as part of the separation assurance process.
Control message transmission	M: The human(s) relays by voice (without critical assessment) computer-displayed clearances and advisories for non-data-link aircraft. A: The computer(s) issues clearances and advisories by data link and forwards flight plan data updates.

*M = man; A = automation.

Aircraft Flight Path Planning Process

7. Monitor changes to traffic flight plans--A

8. Determine a flight path plan for an aircraft--A

The computerized control message automation tracks aircraft trajectories, reviews filed flight plans, checks flight plan compatibility with the sector traffic flow plan and current traffic situation, and accepts the flight plan as filed or modifies it as necessary.

Separation Assurance Decision-Making Process

11. Monitor the routinely changing aircraft situation--A

The computer automatically tracks the movement of air traffic through the sector's airspace.

12. Monitor only routinely changing air traffic situations reported by pilots--M

The controller receives initial call-ins from all aircraft coming into the A/G voice frequency and maintains communications with occasional non-data-link aircraft.

13. Establish automated processing of control intervention actions--M

The enroute or terminal controller inputs information not otherwise available to the computer, such as the status and identity of aircraft in the A/G frequency. He also inputs information to the computer concerning the requests of those few non-data-link aircraft.

15.* Search for an undetected imminent (emergency) conflict situation--A

This function is the automated conflict alert/ATARS/MSAW operation and is performed in parallel with control message automation and control monitoring.

16.* Monitor a computer report of an imminent (emergency) conflict situation--M

If an emergency is flagged (including graphical and message display) by the conflict alert/ATARS/MSAW, the controller maintains awareness of the situation being processed by the automated operation.

*Pertain to conflict alert, ATARS, and MSAW interruptions to routine control activities.

17. Confirm existence or nonexistence of a potential conflict--A

18. Determine a strategy to resolve the potential conflict--A

19. Determine specific clearances and advisories to resolve the potential conflict--A

The computerized control message automation searches for and confirms a potential conflict situation, defines an appropriate strategy to resolve the conflict, and defines specific clearances and advisories to implement the resolution strategy.

Flight Information Decision-Making Process

23. Search for a flight information service action--A

24. Determine specific clearances and advisories to provide flight information service--A

The computerized control message automation identifies all specific clearances and advisories required by the aircraft to proceed along their flight paths (if such information has not been determined as part of the separation assurance process).

Control Message Transmission Process

28. Issue clearances and advisories--A

The computer automatically transmits digitized control instructions to data-link-equipped aircraft.

30. Relay clearances and advisories--M

The controller receives electronically displayed message instructions, communicates by voice with pilots of an occasional non-data-link aircraft or retransmits messages that could not be completed successfully by data link, and updates computer records.

Appendix G

RATING FACTORS AND FACTOR SELECTION PROCEDURE

Appendix G

RATING FACTORS AND FACTOR SELECTION PROCEDURE

Rating Factors

Job Satisfaction and Motivation

Factor 1: Achievement--Work Alignment

Work alignment refers to the feeling of achievement associated with performing a task that is perceived to fit in with the end goal of the ATC system. This implies that the function is neither "paper work," "make-work," nor concerned with the care of ATC-associated machinery or systems, but directly concerned with controlling traffic.

A high rating indicates your feeling that the function is directly associated with the main purpose of the ATC system. A low rating indicates that the controller will not be able to directly relate his performance of the function to ATC.

Factor 2: Recognition

Recognition refers to the perceived credit received by an individual controller for the performance of a particular function.

A high rating here indicates that the function permits task performance visibility or credit for adequate or superior job performance. A low rating indicates that the function provides no mechanism for individual visibility, credit, or identity for average or superior job performance.

Factor 3: Responsibility

Responsibility refers to the sense of personal accountability for the success or efficient execution of a function. While it is not meant to imply that shared responsibility is a negative quality, it is desired to identify the system configurations in which the controller will perceive shared responsibility with the machine.

A high rating on responsibility indicates that the function provides task-oriented accountability and responsibility on an individual basis. A low rating indicates that the function does not allow for task accountability on an individual basis.

Factor 4: Control Authority

Control authority means being able to take the necessary steps to see that a required action is taken or that a required decision is made. This is akin to responsibility; however, here we are concerned with the means that a controller has for performing his functions and the authority given to him for making decisions and taking action.

A high rating indicates that the function involves the necessary control authority for performing assigned tasks and meeting responsibilities. A low rating indicates that this necessary control authority is not provided in regard to the function. This implies, for instance, that there is a perceived action to be taken or decision to be made, but the system configuration does not allow the controller to do it himself, or to ensure that it gets done.

Factor 5: Utilization of Perceived Skills

The utilization of skills means that the function requires or allows the controller to use the relevant and valued skills he perceives he brings to the situation. Such skills may represent both acquired (i.e., learned) and/or native ability.

A high rating indicates that the function requires or allows the controller to apply relevant valued skills to ATC. A low rating indicates that the function requires minimal or no use of valued skills.

Factor 6: Challenge (Discretionary Flexibility

Challenge or discretionary flexibility is the degree to which a function permits a controller to exercise judgment in the selection of response options.

A high rating indicates that the function permits variety, discretion, flexibility, or creativity in its execution. A low rating indicates that the function provides a rigid task environment allowing for no discretion, flexibility, or creativity in its execution.

Factor 7: Performance Feedback

Performance feedback refers to the indications available to the controller as to the effectiveness of his performance of the function. For optimum job performance and personal satisfaction it is best if this feedback is given as close in time as possible to the activity concerned.

A high rating indicates that performance of the function provides timely direct feedback permitting an assessment of performance. Such feedback can be associated with a specific task and is immediately available upon its completion. A low rating indicates that the function does not allow for direct and immediate task-oriented feedback.

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Factor 8: Interest

Interest means that the function is stimulating or interesting, it is the opposite of boredom.

A high rating indicates that the function is interesting or highly motivating. A low rating indicates that the function is uninteresting, boring, or must be performed in a manner that does not simulate motivation.

Man-Machine Interface

Factor 9: Vigilance

Vigilance refers to the frequent or constant attention required of the controller to detect infrequently occurring events over relatively long periods of time.

A high rating indicates that the system is configured such that excessive vigilance is not required. A low rating indicates that performance of the function requires excessive vigilance of the controller (i.e., unaided by his equipment).

Factor 10: Stress

As used herein, stress is a psychological variable resulting from such causes as emotional strain, severe time constraints, workload, and responsibilities.

A high rating on stress indicates that the function performed by the controller in the system at issue produces relatively little emotional strain. A low rating indicates that the function causes severe emotional strain.

Factor 11: Intricacy

Intricacy is the level of activity required by the function as well as its reliance on awkward or complex procedures.

A high rating indicates that execution of the function is straightforward, requiring minimal manual activity or complexity in the inputting of data or executing procedures. A low rating indicates that the function is executed by complex or awkward procedures. It requires prolonged operation interaction or adherence to an intricate sequence of activities.

Factor 12: Restrictiveness

Restrictiveness refers to the inability of the controller to perform parallel or simultaneous functions, tasks, or activities. A restrictive function is one that requires the full attention of the controller and does not permit parallel execution of another function or task (such as scanning the PVD). Another kind of restrictive function is one that requires the simultaneous performance of an excessive number of actions. The net result of a restrictive function is that the controller is much reduced in his ability to respond to stimuli or situations during the performance of it.

A high rating in restrictiveness indicates that the function permits the parallel or simultaneous execution of other functions, tasks, or activities. The execution of one function does not unduly interfere with that of another. A low rating indicates that the function requires the simultaneous performance of an excessive number of tasks or the performance of functions or tasks that interfere with each other.

Factor 13: Rigidity

Rigidity refers to inflexibility in the order of executing tasks and to the time criticality of execution. A flexible function allows the controller an opportunity to order the tasks involved to be executed in a specified time frame (e.g., a task can be delayed in order to devote attention to more critical tasks). A function inflexible in execution mandates a rigid sequence or order in which the tasks must be performed.

A high rating in rigidity indicates a function with high flexibility, one in which the controller has some autonomy and need not respond immediately to each stimulus or machine action. A low rating indicates that the controller's work is more tied to external events or the actions taken by the machine; his work is substantially driven or forced.

Factor 14: Decision Making

Decision making refers to the identification and selection of alternatives. Such a situation could arise as a result of a choice presented by the machine to the controller, as a result of a controller-initiated activity, or as a result of an external event, such as an A/G communication or emergency. This rating refers to the nature of the information provided to the controller by the system and the difficulty in using this for making decisions.

A high rating indicates that decisions can be made in a straightforward manner, with appropriate information and alternatives available to the controller. A low rating indicates that decision making involving the function is difficult. The controller may have available only aggregated or raw information to assist him or the controller must have access to a substantial amount of data or perform time-pressured calculations.

Failure Mode Operations

Factor 15: Failure Recognition

Failure recognition refers to your judgment of the ease of recognizing the failure of a particular piece of machinery, algorithm, or automatic process that prevents the function from being performed. For rating purposes assume that a failure has occurred that affects only the function being rated.

A high rating on recognition indicates that the ATC system provides enough feedback or redundancy to announce the failure in question. A low rating indicates that the failure may not be recognized at all or until a critical situation develops.

Factor 16: Failure Recovery

This refers to your judgment of the ease and efficiency of recovering from failure. Assume for rating purposes that a failure has occurred affecting only the function in question (and has been recognized).

A high rating here means that the loss of information can be easily and quickly recovered through appropriate manual activity. A low rating indicates that the system function is so critical that recovery from failure is very difficult, time consuming, or time pressured. Note that this category does not refer to ATC operations after recovery has been affected and activities have settled down to a "steady-state," but only to the immediate recovery from a failure detection.

Factor 17: Failure Operations

Failure operations refers to your judgment of the quality of ATC operations after a failure has occurred. This means that a malfunction or failure has occurred and been detected, and whatever necessary has already been done to compensate for the failure.

A high rating indicates that the failure in question has little or no impact on ATC operations in that system. A low rating indicates that the system does not easily allow for manual control transfer or capability of overriding automatic function. Overall ATC operations are disrupted because of system inefficiency or performance degradation (less traffic can be handled).

Factor Selection Procedure

The 17 factors were chosen from a group of approximately 30 candidate factors. Some factors were eliminated to reduce the amount of work required of each rater and to avoid overlapping among factors. Other factors were eliminated during pretesting at SRI either because they could

not be related directly to the ATC systems or because they could not be easily distinguished from one another.

The factors that were retained overlap somewhat. This is inevitable due to the lack of precision in the English language. It is an acceptable psychological testing practice to include similar factors as a consistency check. In addition, the list of factors is by no means complete. Whole categories of man/machine interface factors that pertained to purely technological mechanizations were excluded. For example, each of the six systems under consideration uses a CRT display. However, no system can profitably be rated on such factors as CRT brightness or information content, both of which can be influenced by engineering or software changes totally unrelated to automation and its basic effects.

Rating Instructions

The packet of information given to the raters contained the following items:

- An instruction booklet.
- A rater background sheet.
- A set of six booklets containing systems descriptions for the ATC systems to be rated.
- Six rating sheets, one for each ATC system (inverted into the appropriate system booklet).
- A booklet of factors describing the criteria on which to rate the six systems.

Rater Background Sheet

The rater background sheet requested information about the raters' ATC background and experience. It was used for both follow-up contacts and statistical purposes.

System Description Booklets

Each system description booklet contained information about a particular ATC system ranging in sophistication of automation from the current NAS/ARTS system (System 1) to Control-by-Exception Level III (System 6). Each booklet consisted of four parts, each one providing a more detailed description of the system. The first part, a system operational overview, briefly described the system and the level of automation and technology it embodies. Following this was a chart describing control process roles for five processes: sector traffic flow planning, aircraft flight planning, separation assurance decision making, flight information decision making, and control message transmission. The chart identified the roles of both the controller and the automatic machinery in performing these processes.

Parts 3 and 4 of the booklet described the control processes in terms of 30 generalized control functions. The third part of each system description booklet consisted of a list of control functions applicable to that particular system within each control process. Each function was marked with an M (human) or an A (automation). Not all 30 functions were represented in each system; the functions not applicable to the particular system were not included in the booklet for that system. The fourth part of the booklet was simply a more detailed description of each control function. It was anticipated that the raters would read Part 4 of each booklet before they began to score each system, and that, as they progressed through the system, they would need to refer only to Parts 2 or 3.

Rating Sheets

Each of the six systems had a rating sheet (see Appendix H). At the top of each sheet was the system number and its title. Each sheet contained a list of the 30 general control functions broken down into the five control processes. The data were the same for each of the six systems. Each control function represented in the system is described with an M (man) or an A (automation).

The 17 factors by which each system was rated were listed along the top of the rating sheet. These factors are divided into three general areas: achievement and satisfaction, man-machine interface, and post-failure operations. Descriptions of all of these factors could be found in the system factors booklet (see below). System ratings were to be placed in the boxes at the center of the rating sheet. The scores put in a box applied to the control function on the same line as the box and the factor in the same column as the box. Some boxes applied to more than one control function, and the score put in such a box was understood to apply to all control functions covered by that box. The absence of a box for a particular control function or factor indicated either that the control function was not present in that particular system or that a score was not desired for that particular factor.

At the right of each line of boxes extending under the failure mode operations factors was a description of what particular item was to be considered as having failed for that rating. Below the rating boxes was a description of the scoring metrics (rating scales) used for each factor. At the very bottom of each rating sheet was an area in which the raters were encouraged to comment on anything that could not be described by a single rating.

System Factors Booklet

The system factors booklet contained write-ups for each of the 17 factors. The write-up for each factor contained a short definition of the factor and a description of what high and low ratings mean. Recall

that in all cases a high rating indicates a "better" system than a low rating, and ratings from 1 to 5 were to be assigned according to the scales printed on the rating sheets. Additional scoring instructions given to the raters are described below.

Rating Guidelines for Job Satisfaction and Motivation and Man-Machine Interface Factors

The 14 job satisfaction and motivation and man-machine interface factors were rated using the rating metric (rating scale) under the factor being considered. One metric was used for the job satisfaction and motivation factors, and two for the man-machine interface factors. The human (M) functions were to be rated as if the rater were the controller performing them. The raters were cautioned that there is more to rating a function than simply considering that function alone; each function had to be considered in the context of the particular system. Both controller workload and the division of tasks between man and machine inherent in the system also had to be taken into account. For instance, when rating the factor "rigidity," consideration of the time criticality of the function required that the rater be aware of what tasks were being performed by the man at approximately the same time and what tasks were being handled by the computer. The rating given to a particular function for the rigidity factor might vary considerably depending on the perception of the controller workload inherent in the system.

Automation (A) functions were to be rated only for some selected factors within the job satisfaction and motivation category: recognition, responsibility, skill utilization, challenge, and interest. The raters were asked to judge the change in rating from a previous system where the automatic function was performed manually. Therefore, there were two versions of the rating metric for job satisfaction and motivation factors: one for manually performed and one for automatically performed functions. The second definition of the metric referred to the perceived change in the factor rating due to automating the function.

Vigilance and stress were the only factors within the man-machine interface category that were rated for automated tasks. These factors could be rated by the same metric as that used for manually performed functions with the understanding that the controller need no longer perform a particular function.

Rating Failure Mode Operation Factors

Only certain functions were to be rated with respect to failure mode operation factors. Next to each set of boxes in the failure mode factor columns was a description of the failed component group, algorithm, or process.

Appendix H

RATING FORMS

RATING FORM ERRATA

System	Function	Factor	Corrective Action
1	7	Vigilance	Delete scoring box
2	8	Vigilance	Add scoring box
3	28	Vigilance	Delete scoring box
4	30	Alignment	Delete scoring box
5	6	Alignment	Delete scoring box

Results presented in this report are based on the uncorrected rating sheets.

SYSTEM 1: NAS/ARTS

General Process	Control Function
Sector Traffic Flow Planning	1. Monitor changes to the sector operating status
	2.
	3. Determine a sector traffic flow plan
	4.
	5.
	6. Issue the sector traffic flow plan
Aircraft Flight Path Planning	7. Monitor changes to the traffic flight plans
	8. Determine a flight path plan for an aircraft
	9.
	10.
Separation Assurance Decision-Making	11. Monitor the routinely changing air traffic situation
	12.
	13.
	14. Search for a potential control intervention action
	15. Search for an imminent (emergency) conflict situation
	16. Monitor a computer report of an imminent (emergency) conflict situation
	17. Confirm the existence or non-existence of a potential conflict
	18. Determine a strategy to resolve the potential conflict
	19. Determine specific clearances and advisories to resolve the potential conflict
	20.
	21.
	22.
Flight Information Decision-Making	23. Search for a flight information service action (other than separation services)
	24. Determine specific clearances and advisories to provide flight information service
	25.
	26.
	27.
Control Message Transmission	28. Issue clearances and advisories
	29.
	30.

JOB SATISFACTION AND MOTIVATION: Alignment | Recognition | Responsibility | Control Authority | Skill Utilization | Challenge | Feedback | Interest

MAN-MACHINE INTERFACE: Vigilance | Stress | Intricacy | Restrictiveness | Rigidity | Decision Making

FAILURE MODE: Failure Recognition | Failure Recovery | Failure Operations

[illegible] | System | Function

(FPD Fails) — functions 7–8

(FPD Fails) — function 11

(Conflict Alert and RDP Fails) — function 15

(A/G to Gnd A/G Fails) — function 28

Please use the space below to comment on the system, the factors, or any aspect not covered by the ratings above.

For A Functions	For M Functions
A great deal more	A great deal
Somewhat more	Very much
Little difference	Moderate amount
Somewhat less	Very little
A great deal less	Almost none

- Almost none
- Very little
- Moderate amount
- Very much
- A great deal

- Very easy to do
- Easy to do
- Moderately difficult to do
- Difficult to do
- Very difficult to do

- Virtually No Impact
- Slight Impact
- Moderate Impact
- Heavy Impact
- Severe Impact

SYSTEM 2: ENROUTE DECISION AID

Rating columns: JOB SATISFACTION AND MOTIVATION (Alignment, Recognition, Responsibility, Control Authority, Skill Utilization, Challenge, Feedback, Interest); MAN-MACHINE INTERFACE (Vigilance, Stress, Intricacy, Restrictiveness, Rigidity, Decision Making); FAILURE MODE (Failure Recognition, Failure Recovery, Failure Operations); Enter System Function.

General Process	Control Function		
Sector Traffic Flow Planning	1. Monitor changes to the sector operating status	B	
	2.		
	3. Determine a sector traffic flow plan	B	
	4.		
	5.		
	6. Issue the sector traffic flow plan	B	
Aircraft Flight Path Planning	7. Monitor changes to the traffic flight plans	B	
	8. Determine a flight path plan for an aircraft	B	(PVD Fails)
	9.		
	10.		
Separation Assurance Decision-Making	11. Monitor the routinely changing air traffic situation	B	(PVD Fails)
	12.		
	13. Establish an automated processing of control intervention actions	B	
	14.		
	15. Search for an imminent (emergency) conflict situation	A	(Conflict Alert and NBAP Fails)
	16. Monitor a computer report of an imminent (emergency) conflict situation	B	
	17. Confirm the existence or non-existence of a potential conflict	A	
	18. Determine a strategy to resolve the potential conflict	A	
	19. Determine specific clearances and advisories to resolve the potential conflict	A	(Conflict Probe Fails)
	20. Review the computer assessment and recommended resolution of a potential conflict	B	
	21. Review the computer recommended strategy, clearances and advisories to resolve the potential conflict	B	
	22.		
Flight Information Decision-Making	23. Search for a flight information service action (other than separation services)	B	
	24. Determine specific clearances and advisories to provide flight information service	B	
	25.		
	26.		
	27.		
Control Message Transmission	28. Issue clearances and advisories	B	(A/G to the A/C Fails)
	29.		
	30.		

Please use the space below to comment on the system, the factors, or any aspect not covered by the ratings above.

For A Functions	For B Functions
A great deal more	A great deal
Somewhat more	Very much
Little difference	Moderate amount
Somewhat less	Very little
A great deal less	Almost none

Man-Machine Interface scale: Almost none; Very little; Moderate amount; Very much; A great deal

Decision Making / Failure Recognition / Failure Recovery scale: Very easy to do; Easy to do; Moderately difficult to do; Difficult to do; Very difficult to do

Failure Operations scale: Virtually No Impact; Slight Impact; Moderate Impact; Heavy Impact; Severe Impact

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SYSTEM 3: TERMINAL DECISION AID

General Process	Control Function		JOB SATISFACTION AND MOTIVATION								MAN-MACHINE INTERFACE						FAILURE MODE						
			Align-ment	Recog-nition	Respon-sibility	Control Authority	Skill Utili-zation	Challenge	Feed-back	Interest	Vigi-lance	Stress	Intricacy	Restric-tiveness	Rigid-ity	Decision Making	Failure Recognition	Failure Recovery	Failure Operations		Rater	System	Function
Sector Traffic Flow Planning	1. Monitor changes to the sector operating status	M																					
	2. Establish automated processing of a sector traffic flow plan	M																					
	3. Determine a sector traffic flow plan	A																					
	4. Review the computer recommended sector traffic flow plan	M																					
	5. Revise the computer recommended sector traffic flow plan	M																					
	6. Issue the sector traffic flow plan	A																					
Aircraft Flight Path Planning	7. Monitor changes to the traffic flight plans	A																		(Control Message Automation Fails)			
	8. Determine a flight path plan for an aircraft	A																					
	9. Review the computer recommended flight path plan	M																					
	10. Revise the computer recommended flight path plan	M																					
Separation Assurance Decision-Making	11. Monitor the routinely changing air traffic situation	A																		(Control Message Automation Fails)			
	12. Monitor only routinely changing air traffic situations reported by pilots	M																					
	13. Establish an automated processing of control intervention actions	M																					
	14.																						
	15. Search for an imminent (emergency) conflict situation	A																		(Conflict Alert and MSAW Fails)			
	16. Monitor a computer report of an imminent (emergency) conflict situation	M																					
	17. Confirm the existence or non-existence of a potential conflict	A																					
	18. Determine a strategy to resolve the potential conflict	A																					
	19. Determine specific clearances and advisories to resolve the potential conflict	A																		(Metering and Spacing Logic Fails)			
	20. Review the computer assessment and recommended resolution of a potential conflict	M																					
	21. Revise the computer recommended strategy, clearances and advisories to resolve the potential conflict	M																					
	22.																						
Flight Information Decision-Making	23. Search for a flight information service action (other than separation services)	A																		(Metering and Spacing Logic Fails)			
	24. Determine specific clearances and advisories to provide flight information service	A																					
	25. Review the computer recommended action for flight information service	M																					
	26. Determine advisories to supplement the computer recommended clearances	M																					
	27. Revise the computer recommended flight information service action	M																					
Control Message Transmission	28. Issue clearances and advisories	M																		(A/C to One A/C Fails)			
	29.																						
	30.																						

Please use the space below to comment on the system, the factors, or any aspect not covered by the ratings above.

For A Functions	For M Functions
A great deal more	5 A great deal
Somewhat more	4 Very much
Little difference	3 Moderate amount
Somewhat less	2 Very little
A great deal less	1 Almost none

Man-Machine Interface	Failure Recognition / Recovery	Failure Operations
5 Almost none	5 Very easy to do	5 Virtually No Impact
4 Very little	4 Easy to do	4 Slight Impact
3 Moderate amount	3 Moderately difficult to do	3 Moderate Impact
2 Very much	2 Difficult to do	2 Heavy Impact
1 A great deal	1 Very difficult to do	1 Severe Impact

SYSTEM 4: CONTROL BY EXCEPTION LEVEL 1

JOB SATISFACTION AND MOTIVATION: Alignment · Recognition · Responsibility · Control Authority · Skill Utilization · Challenge · Feedback · Interest

MAN-MACHINE INTERFACE: Vigilance · Stress · Intricacy · Restrictiveness · Rigidity · Decision Making

FAILURE MODE: Failure Recognition · Failure Recovery · Failure Operations

Radar · System · Function

Control Process		Control Function		Failure mode
Sector Traffic Flow Planning	1.	Monitor changes to the sector operating status	M	
	2.	Establish automated processing of a sector traffic flow plan	M	
	3.	Determine a sector traffic flow plan	A	
	4.	Review the computer recommended sector traffic flow plan	M	
	5.	Revise the computer recommended sector traffic flow plan	M	
	6.	Issue the sector traffic flow plan	A	
Aircraft Flight Path Planning	7.	Monitor changes to the traffic flight plans	A	(Control Message Automation Fails)
	8.	Determine a flight path plan for an aircraft	A	
	9.	Review the computer recommended flight path plan	M	
	10.	Revise the computer recommended flight path plan	M	
Separation Assurance Decision-Making	11.	Monitor the routinely changing air traffic situation	A	(Control Message Automation Fails)
	12.	Monitor only routinely changing air traffic situations reported by pilots	M	
	13.	Establish an automated processing of control intervention actions	M	
	14.			
	15.	Search for an imminent (emergency) conflict situation	A	(IPC/Conflict Alert and MSAW Fails)
	16.	Monitor a computer report of an imminent (emergency) conflict situation	M	
	17.	Confirm the existence or non-existence of a potential conflict	A	
	18.	Determine a strategy to resolve the potential conflict	A	
	19.	Determine specific clearances and advisories to resolve the potential conflict	A	(Control Message Automation Fails)
	20.	Review the computer assessment and recommended resolution of a potential conflict	M	
	21.	Review the computer recommended strategy, clearances and advisories to resolve the potential conflict	M	
	22.			
Flight Information Decision-Making	23.	Search for a flight information service action (other than separation services)	A	(Control Message Automation Fails)
	24.	Determine specific clearances and advisories to provide flight information service	A	
	25.			
	26.			
	27.			
Control Message Transmission	28.	Issue clearances and advisories	A	(Data Link Fails)
	29.	Review computer transacted clearances and advisories	M	
	30.	Relay clearances and advisories	A	

Please use the space below to comment on the system, the factors, or any aspect not covered by the ratings above.

For A Functions (Job Satisfaction and Motivation): A great deal more · Somewhat more · Little difference · Somewhat less · A great deal less

For M Functions (Job Satisfaction and Motivation): A great deal · Very much · Moderate amount · Very little · Almost none

Man-Machine Interface (Vigilance to Rigidity): Almost none · Very little · Moderate amount · Very much · A great deal

Decision Making, Failure Recognition, Failure Recovery: Very easy to do · Easy to do · Moderately difficult to do · Difficult to do · Very difficult to do

Failure Operations: Virtually No Impact · Slight Impact · Moderate Impact · Heavy Impact · Severe Impact

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SYSTEM 5: CONTROL BY EXCEPTION LEVEL 2

Control Process		Control Function	Type	Failure condition
Sector Traffic Flow Planning	1.	Monitor changes to the sector operating status	B	
	2.	Establish automated processing of a sector traffic flow plan	B	
	3.	Determine a sector traffic flow plan	A	
	4.	Review the computer recommended sector traffic flow plan	B	
	5.			
	6.	Issue the sector traffic flow plan	A	
Aircraft Flight Path Planning	7.	Monitor changes to the traffic flight plans	A	(Control Message Automation Fails)
	8.	Determine a flight path plan for an aircraft	A	
	9.	Review the computer recommended flight path plan	B	
	10.			
Separation Assurance Decision-Making	11.	Monitor the routinely changing air traffic situation	A	(Control Message Automation Fails)
	12.	Monitor only routinely changing air traffic situations reported by pilots	B	
	13.	Establish an automated processing of control intervention actions	B	
	14.			
	15.	Search for an imminent (emergency) conflict situation	A	(IPC/Conflict Alert and MSAW Fails)
	16.	Monitor a computer report of an imminent (emergency) conflict situation	B	
	17.	Confirm the existence or non-existence of a potential conflict	A	
	18.	Determine a strategy to resolve the potential conflict	A	
	19.	Determine specific clearances and advisories to resolve the potential conflict	A	(Control Message Automation Fails)
	20.	Review the computer assessment and recommended resolution of a potential conflict	B	
	21.			
	22.	Review only the computer recommended strategy to resolve the potential conflict	B	
Flight Information Decision-Making	23.	Search for a flight information service action (other than separation services)	A	(Control Message Automation Fails)
	24.	Determine specific clearances and advisories to provide flight information service	A	
	25.			
	26.			
	27.			
Control Message Transmission	28.	Issue clearances and advisories	A	(Data Link Fails)
	29.			
	30.	Relay clearances and advisories	B	

Rating columns:

JOB SATISFACTION AND MOTIVATION: Alignment | Recognition | Responsibility | Control Authority | Skill Utilization | Challenge | Feedback | Interest

MAN-MACHINE INTERFACE: Vigilance | Stress | Intricacy | Restrictiveness | Rigidity | Decision Making

FAILURE MODE: Failure Recognition | Failure Recovery | Failure Operations

Rater | System | Function

Please use the space below to comment on the system, the factors, or any aspect not covered by the ratings above.

For A Functions	For B Functions
A great deal more	A great deal
Somewhat more	Very much
Little difference	Moderate amount
Somewhat less	Very little
A great deal less	Almost none

- Almost none
- Very little
- Moderate amount
- Very much
- A great deal

- Very easy to do
- Easy to do
- Moderately difficult to do
- Difficult to do
- Very difficult to do

- Virtually No Impact
- Slight Impact
- Moderate Impact
- Heavy Impact
- Severe Impact

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SYSTEM 6: CONTROL BY EXCEPTION LEVEL 3

General Process		Control Function		Alignment	Recognition	Responsibility	Control Authority	Skill Utilization	Challenge	Feedback	Interest	Vigilance	Stress	Intricacy	Restrictiveness	Rigidity	Decision Making	Failure Recognition	Failure Recovery	Failure Operations		Sector	System	Function
				JOB SATISFACTION AND MOTIVATION								MAN-MACHINE INTERFACE						FAILURE MODE						
Sector Traffic Flow Planning	1.	Monitor changes to the sector operating status	M																					
	2.	Establish automated processing of a sector traffic flow plan	M																					
	3.	Determine a sector traffic flow plan	A																					
	4.																							
	5.																							
	6.	Issue the sector traffic flow plan	A																					
Aircraft Flight Path Planning	7.	Monitor changes to the traffic flight plans	A																			(Control Message Automation Fails)		
	8.	Determine a flight path plan for an aircraft																						
	9.																							
	10.																							
Separation Assurance Decision-Making	11.	Monitor the routinely changing air traffic situation	A																			(Control Message Automation Fails)		
	12.	Monitor only routinely changing air traffic situations reported by pilots	M																					
	13.	Establish an automated processing of control intervention actions	M																					
	14.																							
	15.	Search for an imminent (emergency) conflict situation	A																			(IPC/Conflict Alert and [illegible] Fails)		
	16.	Monitor a computer report of an imminent (emergency) conflict situation	M																					
	17.	Confirm the existence or non-existence of a potential conflict	A																					
	18.	Determine a strategy to resolve the potential conflict																						
	19.	Determine specific clearances and advisories to resolve the potential conflict																				(Control Message Automation Fails)		
	20.																							
	21.																							
	22.																							
Flight Information Decision-Making	23.	Search for a flight information service action (other than separation services)	A																					
	24.	Determine specific clearances and advisories to provide flight information service																						
	25.																							
	26.																							
	27.																							
Control Message Transmission	28.	Issue clearances and advisories	A																			(Data Link Fails)		
	29.																							
	30.	Relay clearances and advisories	M																					

Please use the space below to comment on the system, the factors, or any aspect not covered by the ratings above.

For A Functions	For M Functions	Man-Machine Interface	Failure Recognition / Recovery	Failure Operations
A great deal more	A great deal	Almost none	Very easy to do	Virtually no impact
Somewhat more	Very much	Very little	Easy to do	Slight impact
Little difference	Moderate amount	Moderate amount	Moderately difficult to do	Moderate impact
Somewhat less	Very little	Very much	Difficult to do	Heavy impact
A great deal less	Almost none	A great deal	Very difficult to do	Severe impact

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Appendix I

RATING DATA SUMMARY

Table I-1

SYSTEM-FUNCTION TABLES OF AVERAGE RATER RESPONSE

FACTOR 1 ALIGNMENT

FUNC / SYSTEM	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	AVE
1	3.3	0.0	3.8	0.0	0.0	3.9	3.3	3.5	0.0	0.0	3.6	0.0	0.0	4.3	0.0	4.4	4.5	4.8	4.8	0.0	0.0	0.0	3.3	3.4	0.0	0.0	0.0	4.0	0.0	0.0	3.9
2	3.6	0.0	4.1	0.0	0.0	3.8	3.4	3.6	0.0	0.0	4.1	0.0	4.0	0.0	0.0	4.1	0.0	0.0	0.0	4.4	4.3	0.0	3.5	3.5	0.0	0.0	0.0	4.2	0.0	0.0	3.9
3	3.3	3.0	0.0	3.3	3.1	0.0	0.0	0.0	3.2	3.0	0.0	3.3	3.6	0.0	0.0	4.3	0.0	0.0	0.0	4.2	4.2	0.0	0.0	0.0	2.9	2.9	3.1	3.6	0.0	0.0	3.4
4	3.6	3.4	0.0	3.8	3.8	0.0	0.0	0.0	3.8	3.8	0.0	3.3	3.5	0.0	0.0	4.3	0.0	0.0	0.0	4.3	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3	3.4	3.7
5	3.4	3.2	0.0	3.0	0.0	2.1	0.0	0.0	2.9	0.0	0.0	2.8	3.4	0.0	0.0	3.9	0.0	0.0	0.0	3.8	0.0	3.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	3.2
6	2.8	2.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.9	3.0	0.0	0.0	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.9	3.0
AVE RESP	3.4	3.1	4.0	3.4	3.4	3.3	3.3	3.6	3.3	3.4	3.9	3.1	3.5	4.3	0.0	4.1	4.5	4.8	4.8	4.2	4.2	3.8	3.4	3.5	2.9	2.9	3.1	3.9	3.3	3.1	

NO. OF SAMPLES

20	0	20	0	0	20	20	20	0	0	20	0	0	20	0	20	20	20	20	0	0	0	20	20	0	0	0	20	0	0
14	0	14	0	0	14	14	14	0	0	14	0	14	0	0	14	0	0	0	14	14	0	14	14	0	0	0	14	0	0
9	9	0	9	9	0	0	0	9	9	0	9	9	0	0	9	0	0	0	9	9	0	0	0	9	9	9	9	0	0
20	20	0	20	20	0	0	0	20	20	0	20	20	0	0	20	0	0	0	20	20	0	0	0	0	0	0	0	20	20
20	20	0	20	0	20	0	0	20	0	0	20	20	0	0	20	0	0	0	20	0	20	0	0	0	0	0	0	0	20
20	20	0	0	0	0	0	0	0	0	0	20	20	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	19

Table I-2

SYSTEM-FUNCTION TABLES OF AVERAGE RATER RESPONSE

FACTOR 2 RECOGNITION

FUNC / SYSTEM	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	AVE
1	2.3	0.0	3.1	0.0	0.0	3.6	2.6	3.1	0.0	0.0	2.8	0.0	0.0	3.5	2.3	3.5	3.8	4.3	4.3	0.0	0.0	0.0	2.5	3.1	0.0	0.0	0.0	3.8	0.0	0.0	3.2
2	2.4	0.0	2.7	0.0	0.0	3.3	2.9	3.1	0.0	0.0	3.1	0.0	3.1	0.0	2.2	3.6	2.4	2.4	2.4	3.8	4.2	0.0	2.7	2.9	0.0	0.0	0.0	3.7	0.0	0.0	3.0
3	2.2	2.6	2.2	2.8	3.0	2.0	1.7	1.7	2.4	3.0	2.0	2.3	2.8	0.0	1.7	3.6	1.7	1.7	1.7	3.0	3.8	0.0	1.6	1.6	2.6	2.7	2.9	3.2	0.0	0.0	2.4
4	2.4	2.6	1.8	2.8	3.5	1.8	1.7	1.7	2.7	3.3	1.6	2.3	2.8	0.0	1.8	2.9	1.9	1.9	1.9	3.1	3.5	0.0	1.5	1.6	0.0	0.0	0.0	1.5	2.4	2.3	2.3
5	2.2	2.4	1.5	2.0	0.0	1.4	1.5	1.5	2.4	0.0	1.4	2.4	2.8	0.0	1.8	2.9	1.6	1.6	1.6	3.3	0.0	3.6	1.5	1.5	0.0	0.0	0.0	1.5	0.0	2.5	2.1
6	2.0	2.4	1.5	0.0	0.0	1.3	1.4	1.4	0.0	0.0	1.4	2.3	2.6	0.0	1.6	2.7	1.5	1.5	1.5	0.0	0.0	0.0	1.5	1.5	0.0	0.0	0.0	1.6	1.0	2.3	1.8
AVE RESP	2.3	2.5	2.2	2.6	3.3	2.3	2.0	2.1	2.5	3.1	2.1	2.3	2.8	3.5	1.9	3.2	2.1	2.2	2.2	3.3	3.8	3.6	1.9	2.0	2.6	2.7	2.9	2.5	1.7	2.4	

NO. OF SAMPLES

20	0	20	0	0	20	20	20	0	0	20	0	0	20	20	20	20	20	20	0	0	0	20	20	0	0	0	20	0	0
14	0	14	0	0	14	14	14	0	0	14	0	14	0	14	14	14	14	14	14	14	0	14	14	0	0	0	14	0	0
9	9	9	9	9	9	9	9	9	9	9	9	9	0	9	9	9	9	9	9	9	0	9	9	9	9	9	9	0	0
20	20	20	20	20	20	20	20	20	20	20	20	20	0	20	20	20	20	20	20	20	0	20	20	0	0	0	20	20	20
20	20	20	20	0	20	20	20	20	0	20	20	20	0	20	20	20	20	20	20	0	20	20	20	0	0	0	20	0	20
20	20	20	0	0	20	20	20	0	0	20	20	20	0	20	20	20	20	20	0	0	0	20	20	0	0	0	19	1	20

Table I-3

SYSTEM-FUNCTION TABLES OF AVERAGE RATER RESPONSE

FACTOR 3 RESPONSIBILITY

FUNC / SYSTEM	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	AVE
1	3.1	0.0	3.8	0.0	0.0	3.8	3.3	3.5	0.0	0.0	3.6	0.0	0.0	4.3	2.8	4.7	4.6	4.8	4.9	0.0	0.0	0.0	3.3	3.5	0.0	0.0	0.0	4.1	0.0	0.0	3.9
2	3.0	0.0	3.8	0.0	0.0	3.6	3.2	3.4	0.0	0.0	3.6	0.0	4.2	0.0	2.5	4.5	3.3	3.3	3.3	4.2	4.6	0.0	3.5	3.7	0.0	0.0	0.0	4.0	0.0	0.0	3.6
3	2.9	3.2	1.7	3.3	3.8	1.8	1.8	1.8	3.3	3.9	1.8	3.3	3.3	0.0	2.2	4.1	2.1	2.1	2.1	4.2	4.4	0.0	1.7	1.7	3.3	3.2	3.3	3.7	0.0	0.0	2.9
4	3.0	3.3	1.9	3.3	3.9	1.8	1.6	1.6	3.4	3.8	1.8	3.3	3.4	0.0	2.1	3.9	1.9	1.9	2.0	3.8	4.1	0.0	1.5	1.6	0.0	0.0	0.0	1.7	3.1	2.9	2.7
5	2.6	2.8	1.8	2.5	0.0	1.8	1.8	1.8	2.8	0.0	1.8	2.8	3.3	0.0	1.9	3.5	2.0	2.0	2.0	3.6	0.0	4.1	1.7	1.7	0.0	0.0	0.0	1.7	0.0	2.8	2.4
6	2.6	2.8	1.6	0.0	0.0	1.5	1.5	1.5	0.0	0.0	1.7	2.8	3.1	0.0	1.7	3.1	1.6	1.6	1.6	0.0	0.0	0.0	1.5	1.5	0.0	0.0	0.0	1.7	1.0	3.0	2.0
AVE RESP	2.9	3.1	2.4	3.1	3.3	2.4	2.2	2.3	3.2	3.8	2.4	3.1	3.5	4.3	2.2	4.0	2.6	2.6	2.6	4.0	4.4	4.1	2.2	2.3	3.3	3.2	3.3	2.8	2.0	2.9	

NO. OF SAMPLES

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
	20	0	20	0	0	20	20	20	0	0	20	0	0	20	20	20	20	20	20	0	0	0	20	20	0	0	0	20	0	0
	14	0	14	0	0	14	14	14	0	0	14	0	14	0	14	14	14	14	14	14	14	0	14	14	0	0	0	14	0	0
	9	9	9	9	9	9	9	9	9	9	9	9	9	0	9	9	9	9	9	9	9	0	9	9	9	9	9	9	0	0
	20	20	20	20	20	20	20	20	20	20	20	20	20	0	20	20	20	20	20	20	20	0	20	20	0	0	0	20	20	20
	20	20	20	20	0	20	20	20	20	0	20	20	20	0	20	20	20	20	20	20	0	20	20	20	0	0	0	20	0	20
	20	20	20	0	0	20	20	20	0	0	20	20	20	0	20	20	20	20	20	0	0	0	20	20	0	0	0	19	1	20

Table I-4

SYSTEM-FUNCTION TABLES OF AVERAGE RATER RESPONSE

FACTOR 4 AUTHORITY/CONTROL

FUNC / SYSTEM	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	AVE
1	0.0	0.0	3.7	0.0	0.0	3.8	3.8	3.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.3	4.5	4.6	0.0	0.0	0.0	0.0	4.1	0.0	0.0	0.0	4.4	0.0	0.0	4.1
2	0.0	0.0	3.6	0.0	0.0	3.6	0.0	3.8	0.0	0.0	0.0	0.0	4.1	0.0	0.0	4.1	0.0	0.0	0.0	0.0	4.2	0.0	0.0	3.9	0.0	0.0	0.0	4.1	0.0	0.0	3.9
3	0.0	3.3	0.0	0.0	3.9	0.0	0.0	0.0	0.0	4.0	0.0	0.0	3.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.2	0.0	0.0	0.0	0.0	3.7	3.8	3.7	0.0	0.0	3.8
4	0.0	3.7	0.0	0.0	4.0	0.0	0.0	0.0	0.0	4.0	0.0	0.0	3.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.1	3.8
5	0.0	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3	3.5
6	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.9	3.0
AVE RESP	0.0	3.3	3.7	0.0	3.9	3.7	3.8	3.9	0.0	4.0	0.0	0.0	3.6	0.0	0.0	4.1	4.3	4.5	4.6	0.0	4.2	3.9	0.0	4.0	0.0	3.7	3.8	4.1	0.0	3.1	

NO. OF SAMPLES

0	0	20	0	0	20	20	20	0	0	0	0	0	0	0	0	20	20	20	0	0	0	0	20	0	0	0	20	0	0
0	0	14	0	0	14	0	14	0	0	0	0	14	0	0	14	0	0	0	0	14	0	0	14	0	0	0	14	0	0
0	9	0	0	9	0	0	0	0	9	0	0	9	0	0	0	0	0	0	0	9	0	0	0	0	9	9	9	0	0
0	20	0	0	20	0	0	0	0	20	0	0	20	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0	0	20
0	20	0	0	0	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0	20
0	20	0	0	0	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20

Table I-5

SYSTEM-FUNCTION TABLES OF AVERAGE RATER RESPONSE

FACTOR 5 SKILL UTILIZATION

FUNC / SYSTEM	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	3.3	0.0	3.8	0.0	0.0	3.6	3.5	4.0	0.0	0.0	3.8	0.0	0.0	4.4	2.7
2	3.6	0.0	3.9	0.0	0.0	3.6	3.7	3.8	0.0	0.0	4.1	0.0	3.6	0.0	2.3
3	3.3	3.3	1.6	3.6	3.8	1.7	1.7	1.7	3.2	3.4	1.9	2.8	2.7	0.0	2.2
4	3.0	3.0	1.5	3.6	3.6	1.9	1.5	1.5	3.6	3.6	1.6	2.9	3.0	0.0	1.8
5	2.6	2.7	1.3	2.5	0.0	1.5	1.4	1.4	2.7	0.0	1.8	2.7	3.0	0.0	1.9
6	2.5	2.6	1.3	0.0	0.0	1.3	1.3	1.3	0.0	0.0	1.5	2.6	2.8	0.0	1.7
AVE RESP	3.1	2.7	2.3	3.2	3.7	2.3	2.2	2.3	3.2	3.5	2.4	2.8	3.0	4.4	2.1

FUNC / SYSTEM	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	AVE
1	4.0	4.6	4.8	4.8	0.0	0.0	0.0	3.1	3.6	0.0	0.0	0.0	3.6	0.0	0.0	3.8
2	4.1	2.9	2.9	2.9	4.5	4.6	0.0	3.3	3.6	0.0	0.0	0.0	3.8	0.0	0.0	3.6
3	3.4	2.1	2.1	2.1	4.1	4.3	0.0	1.9	1.9	3.1	3.1	3.3	3.2	0.0	0.0	2.8
4	3.4	2.0	2.0	2.1	4.3	4.3	0.0	1.5	1.4	0.0	0.0	0.0	1.6	2.8	2.3	2.6
5	3.4	1.9	1.9	1.9	3.9	0.0	4.0	1.4	1.4	0.0	0.0	0.0	1.4	0.0	2.5	2.3
6	2.9	1.6	1.6	1.6	0.0	0.0	0.0	1.3	1.3	0.0	0.0	0.0	1.6	1.0	2.5	1.8
AVE RESP	3.5	2.5	2.6	2.6	4.2	4.4	4.0	2.1	2.2	3.1	3.1	3.3	2.6	1.9	2.4	

NO. OF SAMPLES

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	20	0	20	0	0	20	20	20	0	0	20	0	0	20	20
2	14	0	14	0	0	14	14	14	0	0	14	0	14	0	14
3	9	9	9	9	9	9	9	9	9	9	9	9	9	0	9
4	20	20	20	20	20	20	20	20	20	20	20	20	20	0	20
5	20	20	20	20	0	20	20	20	20	0	20	20	20	0	20
6	20	20	20	0	0	20	20	20	0	0	20	20	20	0	20

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	20	20	20	20	0	0	0	20	20	0	0	0	20	0	0
2	14	14	14	14	14	14	0	14	14	0	0	0	14	0	0
3	9	9	9	9	9	9	0	9	9	9	9	9	9	0	0
4	20	20	20	20	20	20	0	20	20	0	0	0	20	20	20
5	20	20	20	20	20	0	20	20	20	0	0	0	20	0	20
6	20	20	20	20	0	0	0	20	20	0	0	0	19	1	20

Table I-6

SYSTEM-FUNCTION TABLES OF AVERAGE RATER RESPONSE

FACTOR 6 CHALLENGE

FUNC / SYSTEM	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	AVE
1	2.8	0.0	3.4	0.0	0.0	3.0	2.8	3.3	0.0	0.0	2.8	0.0	0.0	3.6	2.8	3.6	4.1	4.5	4.3	0.0	0.0	0.0	2.8	3.1	0.0	0.0	0.0	2.8	0.0	0.0	3.3
2	2.6	0.0	3.6	0.0	0.0	3.0	2.9	3.3	0.0	0.0	3.2	0.0	3.4	0.0	2.3	3.4	2.8	2.8	2.8	4.3	4.6	0.0	3.1	3.1	0.0	0.0	0.0	2.8	0.0	0.0	3.2
3	2.8	2.9	1.6	3.1	3.8	2.0	1.7	1.7	3.0	3.6	1.6	2.8	2.7	0.0	2.1	3.8	2.0	2.0	2.0	3.9	4.4	0.0	1.7	1.8	2.7	3.1	3.2	2.9	0.0	0.0	2.6
4	2.6	2.8	1.5	3.3	3.6	1.8	1.5	1.6	3.1	3.5	1.7	2.6	2.9	0.0	1.9	3.2	1.8	1.8	1.9	3.8	4.3	0.0	1.4	1.4	0.0	0.0	0.0	1.5	2.7	2.1	2.4
5	2.1	2.4	1.4	2.4	0.0	1.4	1.5	1.5	2.3	0.0	1.5	2.3	2.8	0.0	1.8	3.0	1.7	1.7	1.7	3.3	0.0	3.7	1.4	1.4	0.0	0.0	0.0	1.4	0.0	2.3	2.1
6	2.3	2.4	1.2	0.0	0.0	1.3	1.3	1.3	0.0	0.0	1.3	2.4	2.4	0.0	1.4	2.8	1.6	1.6	1.6	0.0	0.0	0.0	1.3	1.3	0.0	0.0	0.0	1.5	1.0	2.3	1.7
AVE RESP	2.5	2.6	2.1	2.9	3.7	2.1	2.0	2.1	2.9	3.5	2.0	2.5	2.9	3.6	2.0	3.3	2.3	2.4	2.4	3.8	4.4	3.7	1.9	2.0	2.7	3.1	3.2	2.2	1.8	2.2	

NO. OF SAMPLES

20	0	20	0	0	20	20	20	0	0	20	0	0	20	20	20	20	20	20	0	0	0	20	20	0	0	0	20	0	0
14	0	14	0	0	13	14	14	0	0	14	0	14	0	14	14	14	14	14	14	14	0	14	14	0	0	0	14	0	0
9	9	9	9	9	9	9	9	9	9	9	9	9	0	9	9	9	9	9	9	9	0	9	9	9	9	9	9	0	0
20	20	20	20	20	20	20	20	20	20	20	20	20	0	20	20	19	19	19	20	20	0	20	20	0	0	0	20	20	20
20	20	20	20	0	20	20	20	20	0	20	20	20	0	20	20	20	20	20	20	0	20	20	20	0	0	0	20	0	20
20	20	20	0	0	20	20	20	0	0	20	20	20	0	20	20	20	20	20	0	0	0	20	20	0	0	0	19	1	20

Table I-7

SYSTEM-FUNCTION TABLES OF AVERAGE RATER RESPONSE

FACTOR 7 FEEDBACK

FUNC / SYSTEM	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	AVE
1	0.0	0.0	2.9	0.0	0.0	3.3	2.8	3.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.1	4.2	4.4	0.0	0.0	0.0	0.0	3.1	0.0	0.0	0.0	3.3	0.0	0.0	3.5
2	0.0	0.0	2.9	0.0	0.0	3.3	0.0	3.5	0.0	0.0	0.0	0.0	3.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.2	0.0	0.0	3.4	0.0	0.0	0.0	3.9	0.0	0.0	3.6
3	0.0	2.8	0.0	0.0	3.7	0.0	3.2	3.2	0.0	3.7	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0	0.0	0.0	0.0	3.6	3.6	3.4	0.0	0.0	3.4
4	0.0	3.3	0.0	0.0	3.6	0.0	0.0	0.0	0.0	3.8	0.0	0.0	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	3.6
5	0.0	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8	3.1
6	0.0	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3	2.9
AVE RESP	0.0	2.9	2.9	0.0	3.6	3.3	3.0	3.3	0.0	3.7	0.0	0.0	3.2	0.0	0.0	0.0	4.1	4.2	4.4	0.0	4.2	3.7	0.0	3.3	0.0	3.6	3.6	3.6	0.0	3.0	

NO. OF SAMPLES

0	0	20	0	0	20	20	20	0	0	0	0	0	0	0	0	20	20	20	0	0	0	0	20	0	0	0	20	0	0
0	0	14	0	0	14	0	14	0	0	0	0	14	0	0	0	0	0	0	0	14	0	0	14	0	0	0	14	0	0
0	9	0	0	9	0	9	9	0	9	0	0	9	0	0	0	0	0	0	0	9	0	0	0	0	9	9	9	0	0
0	20	0	0	20	0	0	0	0	20	0	0	20	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0	0	20
0	20	0	0	0	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0	20
0	20	0	0	0	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20

Table I-8

SYSTEM-FUNCTION TABLES OF AVERAGE RATER RESPONSE

FACTOR 8 INTEREST

FUNC / SYSTEM	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	AVE
1	2.5	0.0	3.4	0.0	0.0	3.1	2.8	3.5	0.0	0.0	2.8	0.0	0.0	3.8	2.8	3.8	4.3	4.7	4.5	0.0	0.0	0.0	2.8	3.1	0.0	0.0	0.0	3.2	0.0	0.0	3.4
2	2.7	0.0	3.2	0.0	0.0	3.1	2.8	3.5	0.0	0.0	3.2	0.0	3.4	0.0	2.4	4.1	3.4	3.4	3.4	4.5	4.7	0.0	2.9	3.0	0.0	0.0	0.0	3.2	0.0	0.0	3.4
3	2.7	2.8	1.8	3.3	3.8	1.8	2.1	2.1	2.9	3.6	1.9	2.8	2.8	0.0	2.6	3.9	2.4	2.4	2.4	3.9	4.4	0.0	1.9	2.0	2.8	3.0	3.2	3.4	0.0	0.0	2.8
4	2.8	2.8	2.0	3.2	3.8	2.1	2.0	2.0	3.1	3.8	1.9	2.8	3.4	0.0	2.2	3.7	2.3	2.3	2.4	3.9	4.3	0.0	1.5	1.6	0.0	0.0	0.0	1.8	2.8	2.4	2.7
5	2.5	2.7	1.8	2.5	0.0	1.7	1.9	1.8	2.5	0.0	1.6	2.4	2.9	0.0	2.1	3.4	2.2	2.2	2.2	3.8	0.0	4.0	1.6	1.6	0.0	0.0	0.0	1.6	0.0	2.6	2.4
6	2.4	2.6	1.5	0.0	0.0	1.5	1.6	1.6	0.0	0.0	1.5	2.4	2.5	0.0	2.0	3.3	1.9	1.9	1.9	0.0	0.0	0.0	1.5	1.5	0.0	0.0	0.0	1.7	1.0	2.6	2.0
AVE RESP	2.6	2.7	2.3	3.0	3.8	2.2	2.2	2.4	2.9	3.7	2.2	2.6	3.0	3.8	2.3	3.7	2.8	2.8	2.8	4.0	4.5	4.0	2.1	2.1	2.8	3.0	3.2	2.5	1.9	2.6	

NO. OF SAMPLES

20	0	20	0	0	20	20	20	0	0	20	0	0	20	20	20	20	20	20	0	0	0	20	20	0	0	0	20	0	0
14	0	14	0	0	14	14	14	0	0	14	0	14	0	14	14	14	14	14	14	14	0	14	14	0	0	0	14	0	0
9	9	9	9	9	9	9	9	9	9	9	9	9	0	9	9	9	9	9	9	9	0	9	9	9	9	9	9	0	0
20	20	20	20	20	20	20	20	20	20	20	20	20	0	20	20	20	20	20	20	20	0	20	20	0	0	0	20	20	20
20	20	20	20	0	20	20	20	20	0	20	20	20	0	20	20	20	20	20	20	0	20	20	20	0	0	0	20	0	20
20	20	20	0	0	19	20	20	0	0	20	20	20	0	20	20	20	20	20	0	0	0	20	20	0	0	0	19	1	20

Table I-9

SYSTEM-FUNCTION TABLES OF AVERAGE RATER RESPONSE

FACTOR 9 VIGILANCE

FUNC / SYSTEM	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	AVE
1	3.0	0.0	0.0	0.0	0.0	0.0	2.5	3.0	0.0	0.0	2.3	0.0	0.0	2.1	3.4	2.8	0.0	0.0	0.0	0.0	0.0	0.0	3.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8
2	2.9	0.0	0.0	0.0	0.0	0.0	2.9	2.9	0.0	0.0	2.5	0.0	0.0	0.0	3.4	2.7	0.0	0.0	0.0	2.3	2.3	0.0	3.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8
3	3.2	0.0	0.0	2.9	2.9	0.0	3.8	3.8	2.6	2.6	4.2	3.2	0.0	0.0	4.0	2.4	0.0	0.0	0.0	2.2	2.1	0.0	4.2	0.0	3.2	3.2	3.1	3.0	0.0	0.0	3.1
4	3.2	0.0	0.0	3.2	3.1	0.0	3.8	3.8	2.9	2.8	3.6	3.1	0.0	0.0	3.8	2.8	0.0	0.0	0.0	2.4	2.3	0.0	4.3	0.0	0.0	0.0	0.0	0.0	3.1	0.0	3.2
5	3.2	0.0	0.0	3.3	0.0	0.0	4.1	4.1	3.3	0.0	3.8	3.1	0.0	0.0	4.3	3.1	0.0	0.0	0.0	2.8	0.0	2.8	4.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	3.6
6	3.3	0.0	0.0	0.0	0.0	0.0	4.1	4.1	0.0	0.0	3.9	3.3	0.0	0.0	3.9	3.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.8
AVE RESP	3.2	0.0	0.0	3.1	3.0	0.0	3.5	3.6	2.9	2.7	3.4	3.2	0.0	2.1	3.8	2.9	0.0	0.0	0.0	2.5	2.2	2.8	3.8	4.0	3.2	3.2	3.1	3.0	3.1	0.0	

NO. OF SAMPLES

20	0	0	0	0	0	2	19	0	0	20	0	0	20	20	20	0	0	0	0	0	0	20	0	0	0	0	0	0	0
14	0	0	0	0	0	14	14	0	0	14	0	0	0	14	14	0	0	0	14	14	0	14	0	0	0	0	0	0	0
9	0	0	9	9	0	9	9	9	9	9	9	0	0	9	9	0	0	0	9	9	0	9	0	9	9	9	9	0	0
20	0	0	20	20	0	20	20	20	20	20	20	0	0	20	20	0	0	0	20	20	0	20	0	0	0	0	0	19	0
20	0	0	20	0	0	20	20	20	0	20	20	0	0	20	20	0	0	0	20	0	20	20	20	0	0	0	0	0	0
20	0	0	0	0	0	20	20	0	0	20	20	0	0	20	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table I-10

SYSTEM-FUNCTION TABLES OF AVERAGE RATER RESPONSE

FACTOR 10 STRESS

FUNC / SYSTEM	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	AVE
1	4.0	0.0	3.6	0.0	0.0	3.7	3.8	3.5	0.0	0.0	3.2	0.0	0.0	2.8	3.3	2.3	2.3	1.9	2.0	0.0	0.0	0.0	3.8	3.8	0.0	0.0	0.0	3.5	0.0	0.0	3.2
2	3.9	0.0	3.4	0.0	0.0	3.6	3.8	3.5	0.0	0.0	3.2	0.0	3.3	0.0	3.2	2.4	3.0	2.9	3.0	2.4	2.1	0.0	3.8	3.6	0.0	0.0	0.0	3.6	0.0	0.0	3.2
3	4.1	4.1	4.8	4.0	3.2	4.7	4.6	4.6	3.8	3.2	4.7	3.6	3.4	0.0	4.2	2.4	3.6	3.6	3.6	2.7	2.1	0.0	4.7	4.9	4.3	4.1	3.6	3.7	0.0	0.0	3.8
4	4.2	3.9	4.2	3.6	3.1	4.3	4.4	4.4	3.6	3.0	4.1	3.7	3.4	0.0	3.6	2.6	3.3	3.2	3.2	2.7	2.3	0.0	4.4	4.3	0.0	0.0	0.0	4.3	3.3	3.8	3.7
5	4.0	4.0	4.6	4.1	0.0	4.6	4.5	4.5	3.9	0.0	4.4	3.8	3.6	0.0	4.0	2.9	3.7	3.7	3.7	2.9	0.0	2.8	4.4	4.4	0.0	0.0	0.0	4.4	0.0	3.9	4.0
6	4.3	4.1	4.6	0.0	0.0	4.5	4.4	4.4	0.0	0.0	4.4	3.8	3.6	0.0	4.3	3.4	4.0	4.0	4.0	0.0	0.0	0.0	4.3	4.3	0.0	0.0	0.0	4.3	5.0	3.9	4.2
AVE RESP	4.1	4.1	4.2	3.9	3.2	4.3	4.2	4.2	3.8	3.1	4.0	3.7	3.5	2.8	3.8	2.7	3.3	3.2	3.3	2.7	2.2	2.8	4.2	4.2	4.3	4.1	3.6	4.0	4.2	3.9	

NO. OF SAMPLES

20	0	20	0	0	20	20	20	0	0	20	0	0	20	19	20	20	20	20	0	0	0	20	20	0	0	0	20	0	0
14	0	14	0	0	14	14	14	0	0	14	0	14	0	14	14	14	14	14	14	14	0	14	14	0	0	0	14	0	0
9	9	9	9	9	9	9	9	9	9	9	9	9	0	9	9	9	9	9	9	9	0	9	9	9	9	9	9	0	0
20	20	20	20	20	20	20	20	20	20	20	20	20	0	20	20	20	20	20	20	20	0	20	20	0	0	0	20	20	20
20	20	20	20	0	20	20	20	20	0	20	20	20	0	20	20	20	20	20	20	0	20	20	20	0	0	0	20	0	20
20	20	20	0	0	20	20	20	0	0	20	20	20	0	20	20	20	20	20	0	0	0	20	20	0	0	0	19	1	20

Table I-11

SYSTEM-FUNCTION TABLES OF AVERAGE RATER RESPONSE

FACTOR 11 INTRICACY

FUNC / SYSTEM	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	AVE
1	4.2	0.0	3.4	0.0	0.0	3.6	3.8	3.4	0.0	0.0	3.7	0.0	0.0	2.9	0.0	3.2	3.0	2.6	2.9	0.0	0.0	0.0	3.9	4.0	0.0	0.0	0.0	3.6	0.0	0.0	3.5
2	3.9	0.0	3.4	0.0	0.0	3.6	3.6	3.4	0.0	0.0	3.5	0.0	3.3	0.0	0.0	3.4	0.0	0.0	0.0	3.0	2.8	0.0	3.5	3.6	0.0	0.0	0.0	3.9	0.0	0.0	3.5
3	4.1	3.6	0.0	3.8	3.2	0.0	0.0	0.0	3.6	3.4	0.0	3.7	3.2	0.0	0.0	3.4	0.0	0.0	0.0	2.9	2.2	0.0	0.0	0.0	3.6	3.2	2.8	3.3	0.0	0.0	3.3
4	3.9	3.5	0.0	3.3	2.8	0.0	0.0	0.0	3.3	2.7	0.0	3.8	3.4	0.0	0.0	3.4	0.0	0.0	0.0	2.9	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.4	4.0	3.3
5	3.8	3.5	0.0	3.6	0.0	0.0	0.0	0.0	3.5	0.0	0.0	3.7	3.4	0.0	0.0	3.2	0.0	0.0	0.0	2.8	0.0	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.8	3.4
6	3.7	3.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.8	3.4	0.0	0.0	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.8	3.6
AVE RESP	3.9	3.6	3.4	3.5	3.0	3.6	3.7	3.4	3.5	3.1	3.6	3.7	3.4	2.9	0.0	3.4	3.0	2.6	2.9	2.9	2.4	2.8	3.7	3.8	3.6	3.2	2.8	3.6	3.4	3.9	

NO. OF SAMPLES

20	0	20	0	0	20	20	20	0	0	20	0	0	20	0	20	20	20	20	0	0	0	20	20	0	0	0	20	0	0
14	0	14	0	0	14	14	14	0	0	14	0	14	0	0	14	0	0	0	14	14	0	14	14	0	0	0	14	0	0
9	9	0	9	9	0	0	0	9	9	0	9	9	0	0	9	0	0	0	9	9	0	0	0	9	9	9	9	0	0
19	20	0	20	20	0	0	0	20	20	0	20	20	0	0	20	0	0	0	20	20	0	0	0	0	0	0	0	20	20
20	20	0	20	0	0	0	0	20	0	0	20	20	0	0	20	0	0	0	20	0	20	0	0	0	0	0	0	0	20
20	20	0	0	0	0	0	0	0	0	0	20	20	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	20

Table I-12

SYSTEM-FUNCTION TABLES OF AVERAGE RATER RESPONSE

FACTOR 12 RESTRICTIVENESS

FUNC / SYSTEM	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	AVE
1	4.2	0.0	3.3	0.0	0.0	3.2	3.8	3.0	0.0	0.0	3.6	0.0	0.0	2.9	0.0	2.3	2.4	2.3	2.3	0.0	0.0	0.0	3.5	3.5	0.0	0.0	0.0	2.8	0.0	0.0	3.1
2	3.9	0.0	3.1	0.0	0.0	3.4	3.7	2.9	0.0	0.0	3.5	0.0	2.9	0.0	0.0	3.0	0.0	0.0	0.0	2.3	2.1	0.0	3.6	3.3	0.0	0.0	0.0	3.1	0.0	0.0	3.1
3	4.3	3.7	0.0	3.9	3.1	0.0	0.0	0.0	4.0	3.1	0.0	4.1	3.2	0.0	0.0	2.1	0.0	0.0	0.0	2.8	2.1	0.0	0.0	0.0	3.6	3.6	3.1	3.4	0.0	0.0	3.3
4	3.8	3.5	0.0	3.7	3.0	0.0	0.0	0.0	3.5	2.9	0.0	3.7	3.4	0.0	0.0	2.7	0.0	0.0	0.0	[illegible].5	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.4	3.3	3.2
5	4.2	3.6	0.0	3.7	0.0	0.0	0.0	0.0	3.8	0.0	0.0	3.8	3.3	0.0	0.0	2.8	0.0	0.0	0.0	2.4	0.0	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.6	3.4
6	3.8	3.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.5	3.4	0.0	0.0	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.6	3.5
AVE RESP	4.0	3.6	3.2	3.8	3.1	3.3	3.7	3.0	3.8	3.0	3.5	3.8	3.2	2.9	0.0	2.7	2.4	2.3	2.3	2.5	2.1	2.2	3.6	3.4	3.6	3.6	3.1	3.1	3.4	3.5	

NO. OF SAMPLES

20	0	20	0	0	20	20	20	0	0	20	0	0	20	0	20	20	20	20	0	0	0	20	20	0	0	0	20	0	0
14	0	14	0	0	14	14	14	0	0	14	0	14	0	0	14	0	0	0	14	14	0	14	14	0	0	0	14	0	0
9	9	0	9	9	0	0	0	9	9	0	9	9	0	0	9	0	0	0	9	9	0	0	0	9	9	9	9	0	0
20	20	0	20	20	0	0	0	20	20	0	20	20	0	0	20	0	0	0	20	20	0	0	0	0	0	0	0	20	20
20	20	0	20	0	0	0	0	20	0	0	20	20	0	0	20	0	0	0	20	0	20	0	0	0	0	0	0	0	20
20	20	0	0	0	0	0	0	0	0	0	20	20	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	20

Table I-13

SYSTEM-FUNCTION TABLES OF AVERAGE RATER RESPONSE

FACTOR 13 RIGIDITY

FUNC	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
SYSTEM																															AVE
1	3.6	0.0	3.3	0.0	0.0	3.0	3.7	3.1	0.0	0.0	3.3	0.0	0.0	2.8	0.0	1.9	2.0	2.1	2.3	0.0	0.0	0.0	3.6	3.4	0.0	0.0	0.0	2.9	0.0	0.0	2.9
2	3.4	0.0	3.6	0.0	0.0	3.1	3.3	3.4	0.0	0.0	3.0	0.0	2.7	0.0	0.0	2.1	0.0	0.0	0.0	2.7	2.6	0.0	3.7	3.7	0.0	0.0	0.0	2.7	0.0	0.0	3.1
3	3.8	3.3	0.0	3.6	3.1	0.0	0.0	0.0	4.0	3.4	0.0	3.7	3.2	0.0	0.0	2.0	0.0	0.0	0.0	2.4	2.1	0.0	0.0	0.0	3.6	3.4	3.1	2.9	0.0	0.0	3.2
4	3.5	3.2	0.0	3.4	3.0	0.0	0.0	0.0	3.3	2.9	0.0	3.5	3.1	0.0	0.0	2.3	0.0	0.0	0.0	2.4	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	3.1	3.0
5	3.3	3.1	0.0	3.3	0.0	0.0	0.0	0.0	3.2	0.0	0.0	3.3	3.2	0.0	0.0	2.4	0.0	0.0	0.0	2.3	0.0	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8	2.9
6	3.3	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.1	3.0	0.0	0.0	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.1	3.0
AVE RESP	3.5	3.2	3.4	3.4	3.1	3.1	3.5	3.2	3.5	3.2	3.2	3.4	3.1	2.8	0.0	2.2	2.0	2.1	2.3	2.5	2.3	2.1	3.7	3.6	3.6	3.4	3.1	2.8	3.0	3.0	

NO. OF SAMPLES

20	0	20	0	0	20	20	20	0	0	20	0	0	20	0	20	20	20	20	0	0	0	20	20	0	0	0	20	0	0
14	0	14	0	0	14	14	14	0	0	14	0	14	0	0	14	0	0	0	14	14	0	14	14	0	0	0	14	0	0
9	9	0	9	9	0	0	0	9	9	0	9	9	0	0	9	0	0	0	9	9	0	0	0	9	9	9	9	0	0
20	20	0	20	20	0	0	0	20	20	0	20	20	0	0	20	0	0	0	20	20	0	0	0	0	0	0	0	20	20
20	20	0	20	0	0	0	0	20	0	0	20	20	0	0	20	0	0	0	20	0	20	0	0	0	0	0	0	0	20
20	20	0	0	0	0	0	0	0	0	0	20	20	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	20

Table I-14

SYSTEM-FUNCTION TABLES OF AVERAGE RATER RESPONSE

FACTOR 14 DECISION

FUNC	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	AVE
SYSTEM																															
1	0.0	0.0	3.4	0.0	0.0	3.7	0.0	3.5	0.0	0.0	0.0	0.0	0.0	3.1	0.0	0.0	2.9	2.6	2.7	0.0	0.0	0.0	3.5	3.7	0.0	0.0	0.0	3.9	0.0	0.0	3.3
2	0.0	0.0	3.6	0.0	0.0	3.9	0.0	3.4	0.0	0.0	0.0	0.0	3.5	0.0	0.0	0.0	0.0	0.0	0.0	2.8	2.6	0.0	3.5	3.6	0.0	0.0	0.0	3.7	0.0	0.0	3.4
3	0.0	4.0	0.0	4.2	3.4	0.0	0.0	0.0	4.0	3.3	0.0	0.0	3.8	0.0	0.0	0.0	0.0	0.0	0.0	3.2	2.6	0.0	0.0	0.0	4.0	3.8	3.1	3.7	0.0	0.0	3.6
4	0.0	3.9	0.0	3.5	3.2	0.0	0.0	0.0	3.3	3.0	0.0	0.0	3.5	0.0	0.0	0.0	0.0	0.0	0.0	3.1	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.8	0.0	3.3
5	0.0	4.1	0.0	3.9	0.0	0.0	0.0	0.0	3.8	0.0	0.0	0.0	3.4	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	2.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.4
6	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0
AVE RESP	0.0	4.0	3.5	3.9	3.3	3.8	0.0	3.5	3.7	3.2	0.0	0.0	3.6	3.1	0.0	0.0	2.9	2.6	2.7	3.0	2.6	2.4	3.5	3.6	4.0	3.8	3.1	3.8	3.8	0.0	

NO. OF SAMPLES

	0	0	20	0	0	20	0	20	0	0	0	0	0	20	0	0	20	20	20	0	0	0	20	20	0	0	0	20	0	0
	0	0	14	0	0	14	0	14	0	0	0	0	14	0	0	0	0	0	0	14	14	0	14	14	0	0	0	14	0	0
	0	9	0	9	9	0	0	0	9	9	0	0	9	0	0	0	0	0	0	9	9	0	0	0	9	9	9	9	0	0
	0	20	0	20	20	0	0	0	20	20	0	0	20	0	0	0	0	0	0	20	20	0	0	0	0	0	0	0	20	0
	0	20	0	19	0	0	0	0	19	0	0	0	19	0	0	0	0	0	0	19	0	19	0	0	0	0	0	0	0	0
	0	20	0	0	0	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table I-15

SYSTEM-FUNCTION TABLES OF AVERAGE RATER RESPONSE

FACTOR 15 FAILURE RECOGNITION

FUNC / SYSTEM	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	AVE
1	0.0	0.0	2.0	0.0	0.0	1.0	4.0	0.0	0.0	0.0	4.1	0.0	0.0	0.0	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.9	0.0	0.0	2.9
2	0.0	0.0	2.0	0.0	0.0	1.0	3.7	0.0	0.0	0.0	4.0	0.0	0.0	0.0	2.4	0.0	0.0	0.0	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3	0.0	0.0	2.7
3	0.0	0.0	0.0	0.0	0.0	0.0	3.9	0.0	0.0	0.0	3.9	0.0	0.0	0.0	2.4	0.0	0.0	0.0	3.3	0.0	0.0	0.0	3.6	0.0	0.0	0.0	0.0	3.3	0.0	0.0	3.4
4	0.0	0.0	0.0	0.0	0.0	0.0	3.8	0.0	0.0	0.0	3.8	0.0	0.0	0.0	2.8	0.0	0.0	0.0	3.3	0.0	0.0	0.0	3.3	0.0	0.0	0.0	0.0	3.7	0.0	0.0	3.4
5	0.0	0.0	0.0	0.0	0.0	0.0	3.6	0.0	0.0	0.0	3.4	0.0	0.0	0.0	2.4	0.0	0.0	0.0	2.9	0.0	0.0	0.0	3.1	0.0	0.0	0.0	0.0	3.1	0.0	0.0	3.1
6	0.0	0.0	0.0	0.0	0.0	0.0	3.3	0.0	0.0	0.0	3.1	0.0	0.0	0.0	2.3	0.0	0.0	0.0	2.8	0.0	0.0	0.0	2.9	0.0	0.0	0.0	0.0	3.5	3.0	0.0	3.0
AVE RESP	0.0	0.0	2.0	0.0	0.0	1.0	3.7	0.0	0.0	0.0	3.7	0.0	0.0	0.0	2.5	0.0	0.0	0.0	3.0	0.0	0.0	0.0	3.2	0.0	0.0	0.0	0.0	3.5	3.0	0.0	

NO. OF SAMPLES

0	0	1	0	0	1	20	0	0	0	20	0	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	19	0	0
0	0	1	0	0	1	14	0	0	0	14	0	0	0	14	0	0	0	13	0	0	0	0	0	0	0	0	13	0	0
0	0	0	0	0	0	9	0	0	0	9	0	0	0	9	0	0	0	9	0	0	0	9	0	0	0	0	9	0	0
0	0	0	0	0	0	20	0	0	0	20	0	0	0	20	0	0	0	20	0	0	0	20	0	0	0	0	20	0	0
0	0	0	0	0	0	20	0	0	0	20	0	0	0	20	0	0	0	20	0	0	0	20	0	0	0	0	20	0	0
0	0	0	0	0	0	20	0	0	0	20	0	0	0	20	0	0	0	20	0	0	0	18	0	0	0	0	19	1	0

Table I-16

SYSTEM-FUNCTION TABLES OF AVERAGE RATER RESPONSE

FACTOR 16 FAILURE RECOVERY

FUNC	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
SYSTEM																															AVE
1	0.0	0.0	3.0	0.0	0.0	1.0	2.8	0.0	0.0	0.0	2.4	0.0	0.0	0.0	3.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8	0.0	0.0	2.5
2	0.0	0.0	3.0	0.0	0.0	2.0	2.8	0.0	0.0	0.0	2.2	0.0	0.0	0.0	2.9	0.0	0.0	0.0	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0	2.6
3	0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0	0.0	0.0	2.8	0.0	0.0	0.0	3.1	0.0	0.0	0.0	2.8	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	2.7	0.0	0.0	2.9
4	0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0	0.0	0.0	2.7	0.0	0.0	0.0	2.5	0.0	0.0	0.0	2.3	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	3.1	0.0	0.0	2.7
5	0.0	0.0	0.0	0.0	0.0	0.0	2.8	0.0	0.0	0.0	2.8	0.0	0.0	0.0	2.5	0.0	0.0	0.0	2.5	0.0	0.0	0.0	2.9	0.0	0.0	0.0	0.0	2.8	0.0	0.0	2.7
6	0.0	0.0	0.0	0.0	0.0	0.0	2.4	0.0	0.0	0.0	2.3	0.0	0.0	0.0	2.1	0.0	0.0	0.0	2.0	0.0	0.0	0.0	2.6	0.0	0.0	0.0	0.0	2.4	3.0	0.0	2.4
AVE RESP	0.0	0.0	3.0	0.0	0.0	1.5	2.7	0.0	0.0	0.0	2.5	0.0	0.0	0.0	2.7	0.0	0.0	0.0	2.5	0.0	0.0	0.0	2.9	0.0	0.0	0.0	0.0	2.7	3.0	0.0	

NO. OF SAMPLES

0	0	1	0	0	1	20	0	0	0	20	0	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	19	0	0
0	0	1	0	0	1	14	0	0	0	14	0	0	0	14	0	0	0	13	0	0	0	0	0	0	0	0	13	0	0
0	0	0	0	0	0	9	0	0	0	9	0	0	0	9	0	0	0	9	0	0	0	9	0	0	0	0	9	0	0
0	0	0	0	0	0	20	0	0	0	20	0	0	0	20	0	0	0	20	0	0	0	20	0	0	0	0	20	0	0
0	0	0	0	0	0	20	0	0	0	20	0	0	0	20	0	0	0	20	0	0	0	20	0	0	0	0	20	0	0
0	0	0	0	0	0	20	0	0	0	20	0	0	0	20	0	0	0	20	0	0	0	18	0	0	0	0	19	1	0

Table I-17

SYSTEM-FUNCTION TABLES OF AVERAGE RATER RESPONSE

FACTOR 17 FAILURE OPERATIONS

FUNC / SYSTEM	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	AVE
1	0.0	0.0	2.0	0.0	0.0	1.0	2.6	0.0	0.0	0.0	2.1	0.0	0.0	0.0	3.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.7	0.0	0.0	2.3
2	0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0	0.0	0.0	2.4	0.0	0.0	0.0	3.4	0.0	0.0	0.0	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	0.0	0.0	3.1
3	0.0	0.0	0.0	0.0	0.0	0.0	3.3	0.0	0.0	0.0	3.1	0.0	0.0	0.0	3.4	0.0	0.0	0.0	3.0	0.0	0.0	0.0	3.6	0.0	0.0	0.0	0.0	3.2	0.0	0.0	3.3
4	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0	2.9	0.0	0.0	0.0	2.8	0.0	0.0	0.0	2.6	0.0	0.0	0.0	3.1	0.0	0.0	0.0	0.0	2.8	0.0	0.0	2.9
5	0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0	0.0	0.0	2.8	0.0	0.0	0.0	2.5	0.0	0.0	0.0	2.5	0.0	0.0	0.0	3.2	0.0	0.0	0.0	0.0	2.8	0.0	0.0	2.8
6	0.0	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0	2.3	0.0	0.0	0.0	2.1	0.0	0.0	0.0	1.9	0.0	0.0	0.0	2.6	0.0	0.0	0.0	0.0	2.3	3.0	0.0	2.4
AVE RESP	0.0	0.0	2.0	0.0	0.0	1.0	2.9	0.0	0.0	0.0	2.6	0.0	0.0	0.0	2.9	0.0	0.0	0.0	2.7	0.0	0.0	0.0	3.1	0.0	0.0	0.0	0.0	2.9	3.0	0.0	

NO. OF SAMPLES

0	0	1	0	0	1	20	0	0	0	20	0	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	18	0	0
0	0	0	0	0	0	14	0	0	0	14	0	0	0	14	0	0	0	13	0	0	0	0	0	0	0	0	13	0	0
0	0	0	0	0	0	9	0	0	0	9	0	0	0	9	0	0	0	9	0	0	0	9	0	0	0	0	9	0	0
0	0	0	0	0	0	20	0	0	0	20	0	0	0	20	0	0	0	20	0	0	0	20	0	0	0	0	20	0	0
0	0	0	0	0	0	20	0	0	0	20	0	0	0	20	0	0	0	20	0	0	0	20	0	0	0	0	20	0	0
0	0	0	0	0	0	20	0	0	0	20	0	0	0	20	0	0	0	20	0	0	0	19	0	0	0	0	19	1	0

Appendix J

BIAS ADJUSTMENT CALCULATIONS

Appendix J

BIAS ADJUSTMENT CALCULATIONS

A mathematical statement of the bias manipulations follows:

r_{ijkl} is the k'th rater's score for the i'th factor and the j'th function of the l'th system.

b_{ik} is the average score for the i'th factor by the k'th rater.

N_{ijl} is the set of raters scoring item i,j,l.

$|N_{ijl}|$ is the number of raters in N_{ijl}.

$S^{(i)}_{lj}$ is the entry of the l'th row, j'th column of Table i.

$C^{(i)}_{lj}$ is the entry of the l'th row, j'th column of the (unbiased) comparison table for Table i.

For two systems l and l' of Table i's j'th column we have:

$$S^{(i)}_{lj} = \frac{1}{|N_{ijl}|} \sum_{k \in N_{ijl}} r_{ijkl}$$

and

$$S^{(i)}_{l'j} = \frac{1}{|N_{ijl}|} \sum_{k \in N_{ijl'}} r_{ijkl} \quad .$$

Let $n = |N_{ijl}|$ and $n' = |N_{ijl'}|$.

Then, for the "unbiased" scores,

$$C_{lj}^{(i)} = \frac{1}{n} \sum_{k \in N_{ijl}} (r_{ijkl} - b_{ik})$$

$$= S_{lj}^{(i)} - \frac{1}{n} \sum_{k \in N_{ijl}} b_{ik}$$

$$= S_{l'j}^{(i)} - \overline{b_{il}} \quad ,$$

where $\overline{b_{il}}$ is the average score (over the raters in N_{ijl}) for factor i. Similarly:

$$C_{l'j}^{(i)} = S_{l'j}^{(i)} - \overline{b_{il'}} \quad .$$

We see that comparing $S_{lj}^{(i)}$ with $S_{l'j}^{(i)}$ is equivalent to comparing $C_{lj}^{(i)}$ with $C_{l'j}^{(i)}$ if and only if $\overline{b_{il}} = \overline{b_{il'}}$, and we can be sure of that only if $N_{ijl} = N_{ijl'}$ (i.e., the two systems are rated by the same raters for factor i).

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